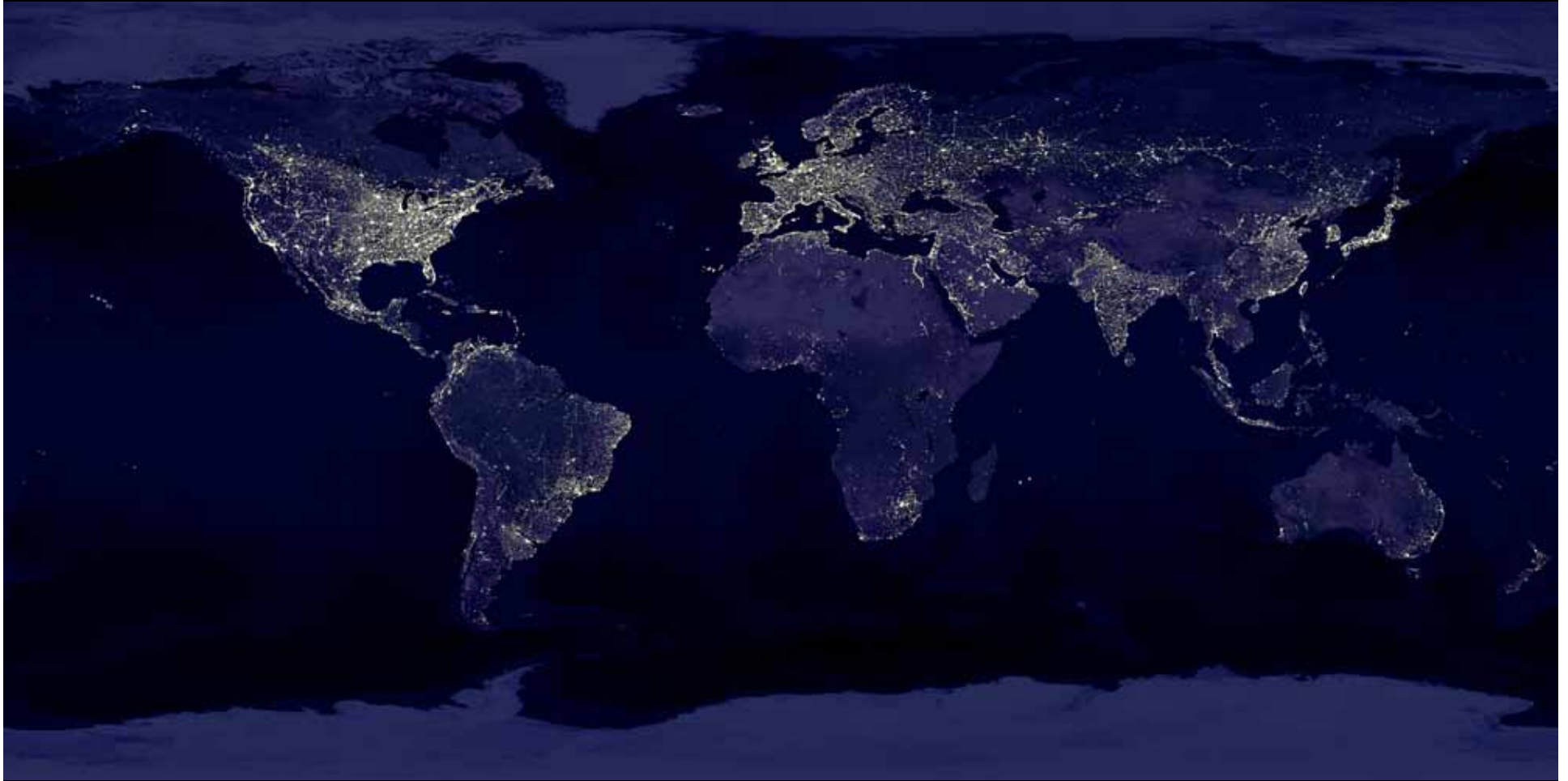


The Specter of Fuel-Based Lighting



Evan Mills, Ph.D.
Lawrence Berkeley National Laboratory

Overview

- The Challenge
- The “Market” & Baseline Technologies
- Precursors
- Solutions
- Prototyping & Deployment
- Product Quality Issues
- Market Deployment

The Challenge

**“We will make electricity so cheap
that only the rich will burn candles”**

- Thomas Edison



**As of 2000: in the developing world, 14% of
urban households and 49% of rural
households had no electricity ...**

Photo: Evan Mills ©

... In fact, there are more non-electrified households today than the total number in Edison's time.

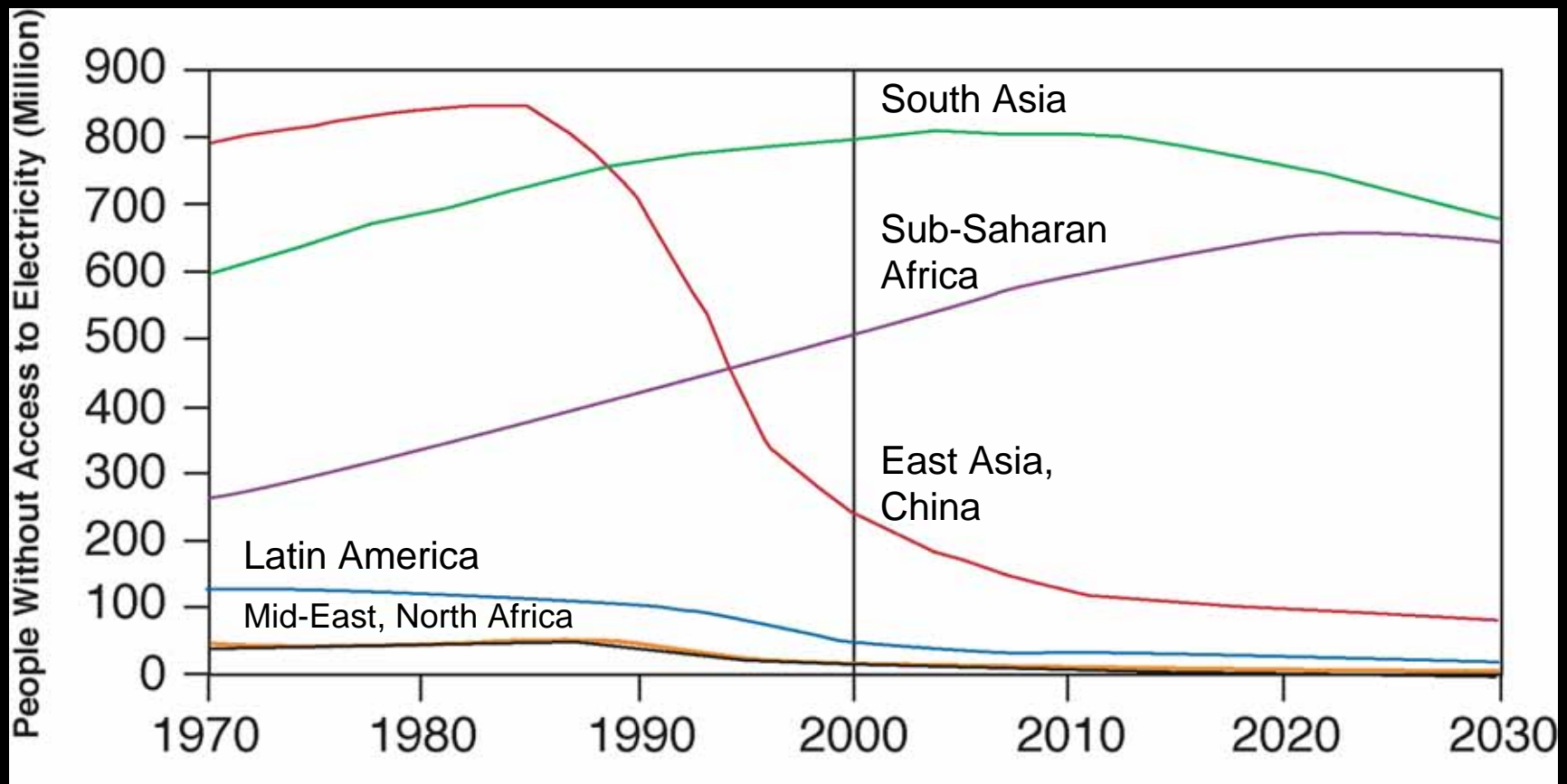


Ghana

Photo: Rick Wilk

Non-electrified Population is Falling Only 0.4%/year

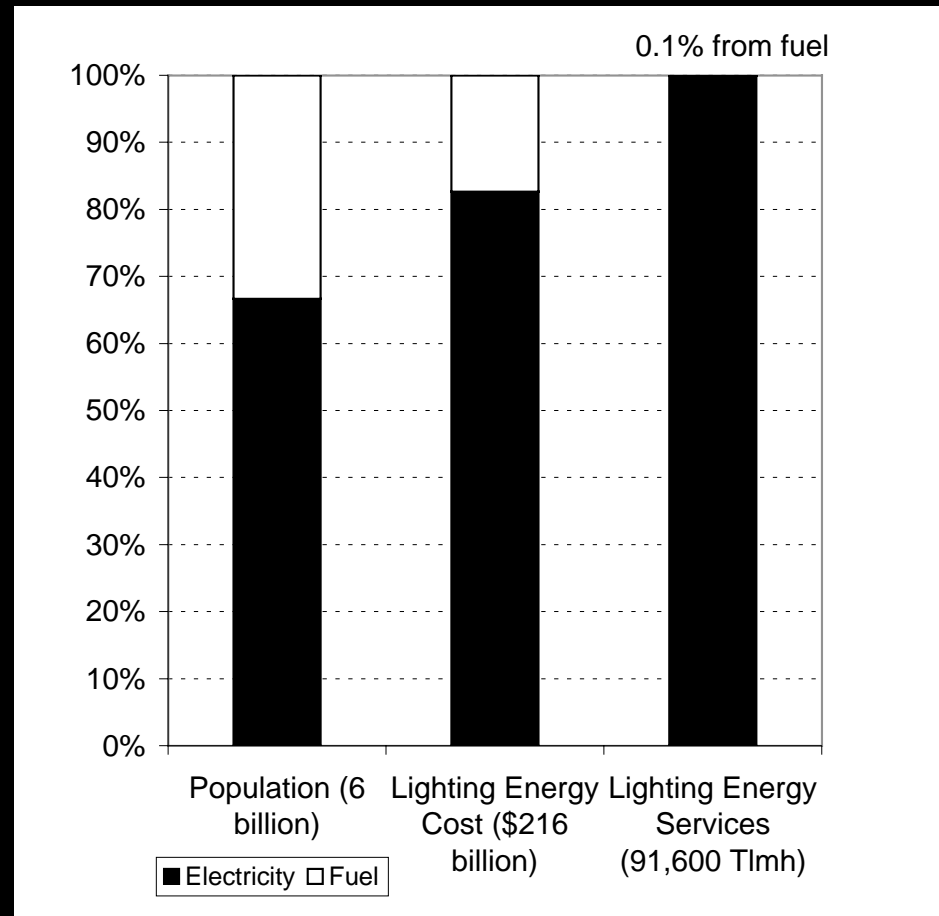
- Excluding China, population is growing faster than electrification, e.g. 4-x faster in Sub-Saharan Africa



Source: International Energy Agency

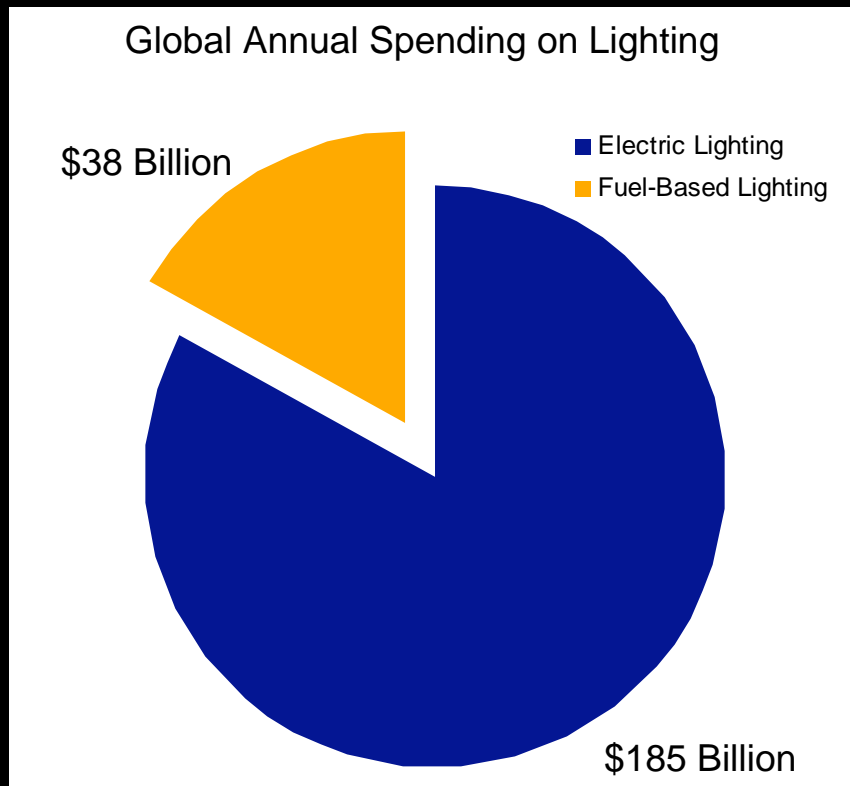
Lighting Inequities

Although one in three people obtain light with kerosene and other fuels - **paying \$40 billion/year** - about 20% of global lighting costs, they receive only 0.1% of the resulting lighting energy services



LBNL Analysis

ALREADY a Large, “Functioning” Market



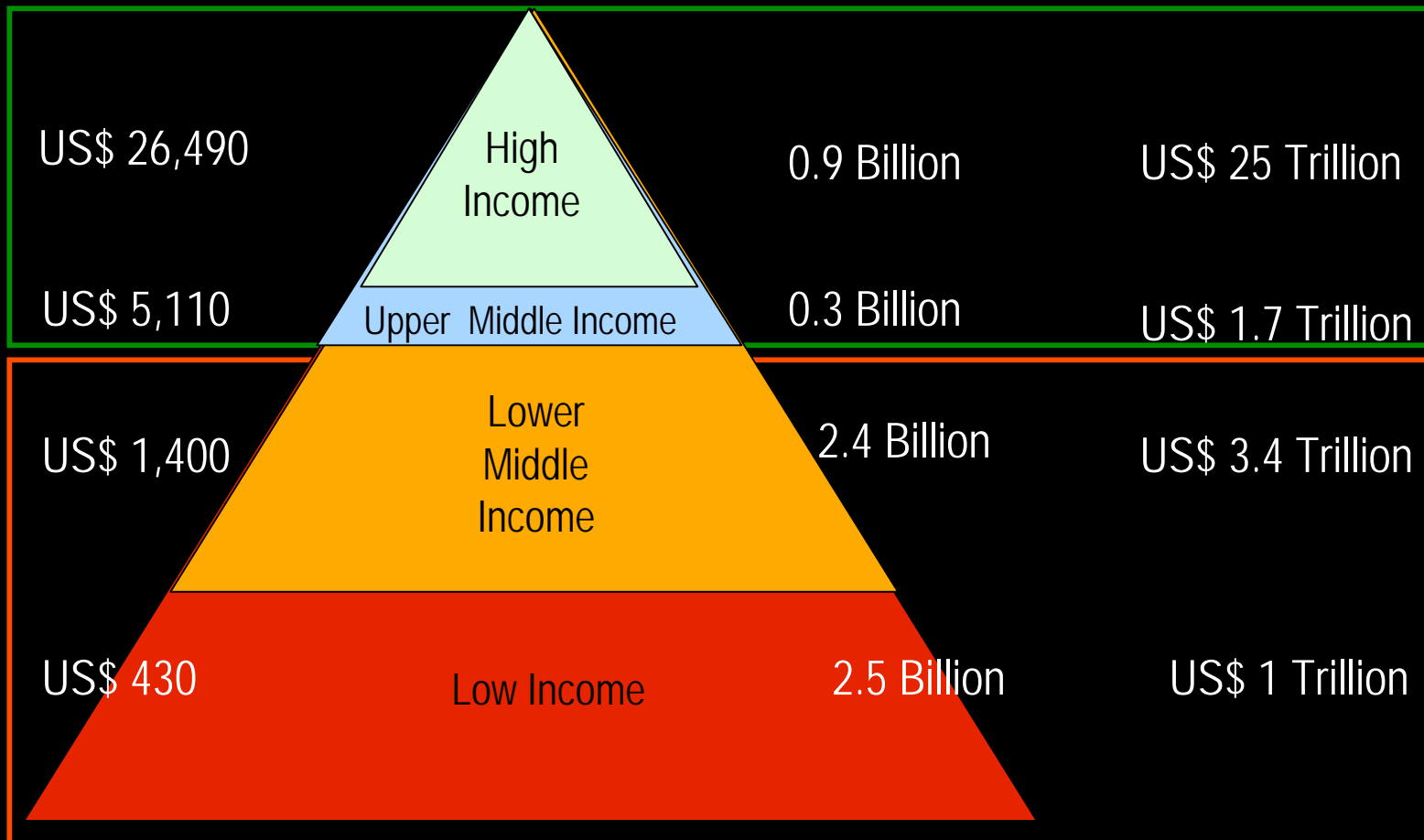
- It is a **commercial, functioning market**, with an established value-chain, collection systems, “technical support”, access to spare parts, repairs services, etc.

The \$40B Lighting Market at the Bottom of the Pyramid

GNI/per capita

Population

Income



Lighting
Market
Dominated
By Electricity

Lighting
Market
Dominated by
Fuels

Note: Based on the "The Fortune at the Bottom of the Pyramid", C.K. Prahalad and
World Bank Development Indicators, 2004

Inferior Service Levels

Illustrative field measurements of non-electrified lighting conditions versus recommended illumination levels*

Area & Task	Recommended illuminance levels	Non-electrified end users (measured Illuminance)
Classroom, desk, printed	300 to 500 lux (horizontal)	6 to 111
Classroom, blackboard	500 lux (vertical)	90 to 207 (daytime)
Retail	500 lux (horizontal)	<1 to 10 lux
Residence, kitchen	300 lux (horizontal)	<1 to 3 lux
Residence, dining	50 lux (horizontal)	<1 to 3 lux

* Notes: Recommendations vary by country. Those shown here are from the North American Illuminating Engineering Society. Measures of illuminance: 1 lux = 1 lumen per square meter; Conversion: 10 lux ~ 1 footcandle.

Greenhouse Gas Emissions



- Per Lantern:
100 kg CO₂/year
 - 40-times as much per unit of light as incandescent lamp;
180- times as much as compact fluorescent lamp
- Globally:
190 million tonnes CO₂/year
 - would be 8th most-emitting “country”

Environmental Dimensions

Environmental issues associated with the provision of illumination in unelectrified contexts.

Lighting Technology	Solid waste (batteries)	Outdoor air pollution	Indoor air pollution	Deforestation	Other
Flashlights ("Torches")	x				
Kerosene					
simple cylindrical wick ("tin")		x	x		
standard hurricane lantern		x	x		
pressurized lantern		x	x		x (*)
LPG		x	x		x (*)
Diesel		x	x		
Candles		x	x		
Biofuel [wood, dung, crop residues, yak butter, other]		x	x	x	
Traditional solar lighting	x				

(*) mantles

Drivers of Innovation

- High cost, low-efficiency, low-quality service
- Poor lighting perpetuates illiteracy
- Fire safety, indoor pollution, deforestation, global warming
- Hardships for women and children (e.g. safety in refugee camps and slums)
- Burden on small enterprises
 - Poor illumination on goods in night markets
 - Poor conditions for hand work
 - Wind, rain impose darkness

The “Market” & Baseline Technologies

Kitchen: 2% Recommended Lighting Level



Small & Medium Enterprises (SMEs)



India: street vendor



Tanzania: night market

Street Hawkers; Kiosks



Tanzania



Kenya

- Classroom light levels as low as 2% of western standards



Kenya (Kibera Slum - flash photo)

- Teachers grading homework with light levels 1% of western standards



Tanzania (Periurban Area)

Egg Farmers



Kenya: small egg farm in rural village

Fishing



Tanzania: 12 hours/day night fishing

Refugee Camps



Photo: Salgado

Wick Lanterns



Merchant (Candle)

Bhutan



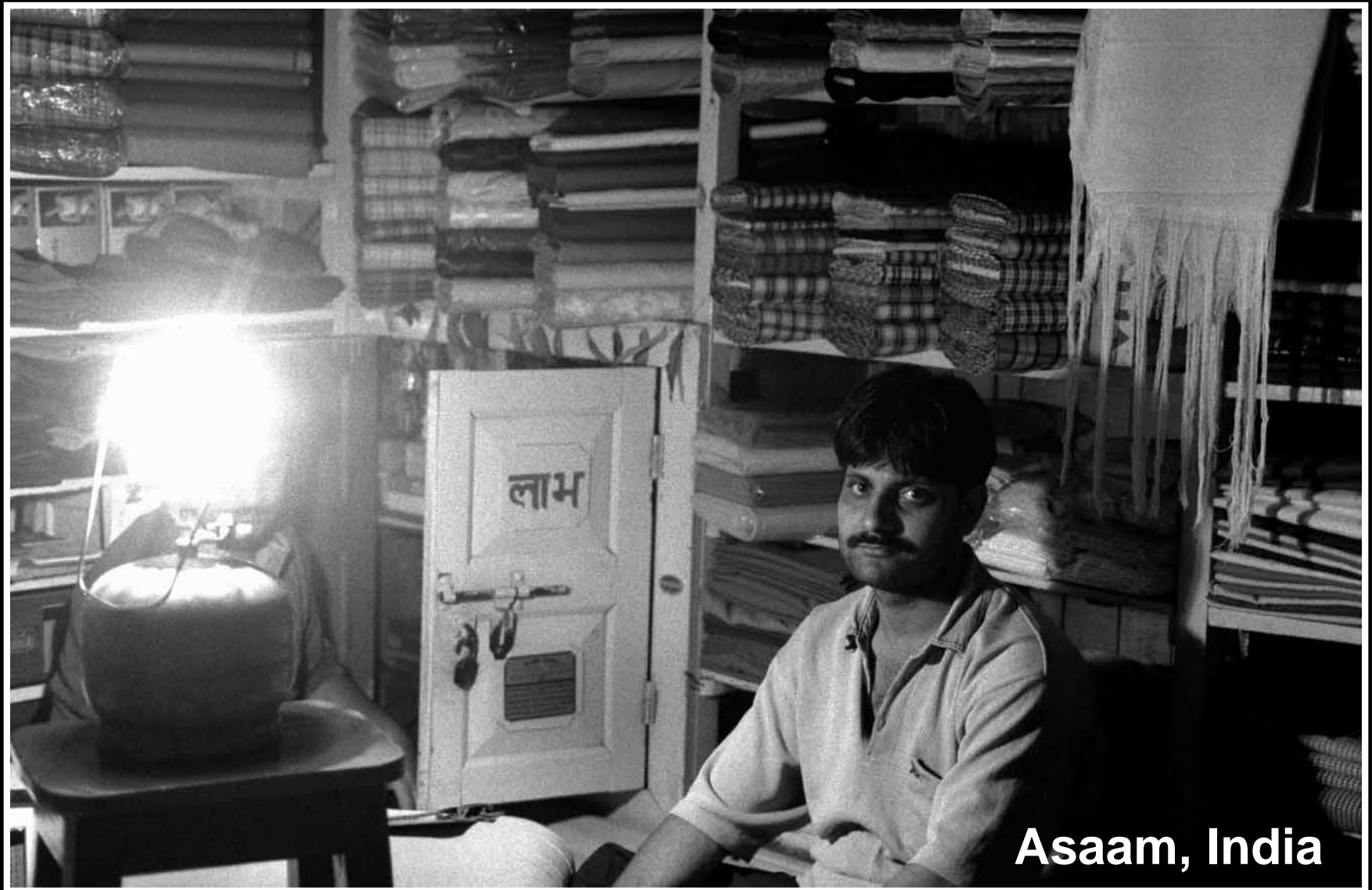
Photo: Evan Mills ©

Market (Candles)



Cambodia

Textile Seller (Propane Mantle Lamp)



Asaam, India

Dri Butter

(their husbands are called Yaks)



Nepal



Whale and Seal Oil



Greenland

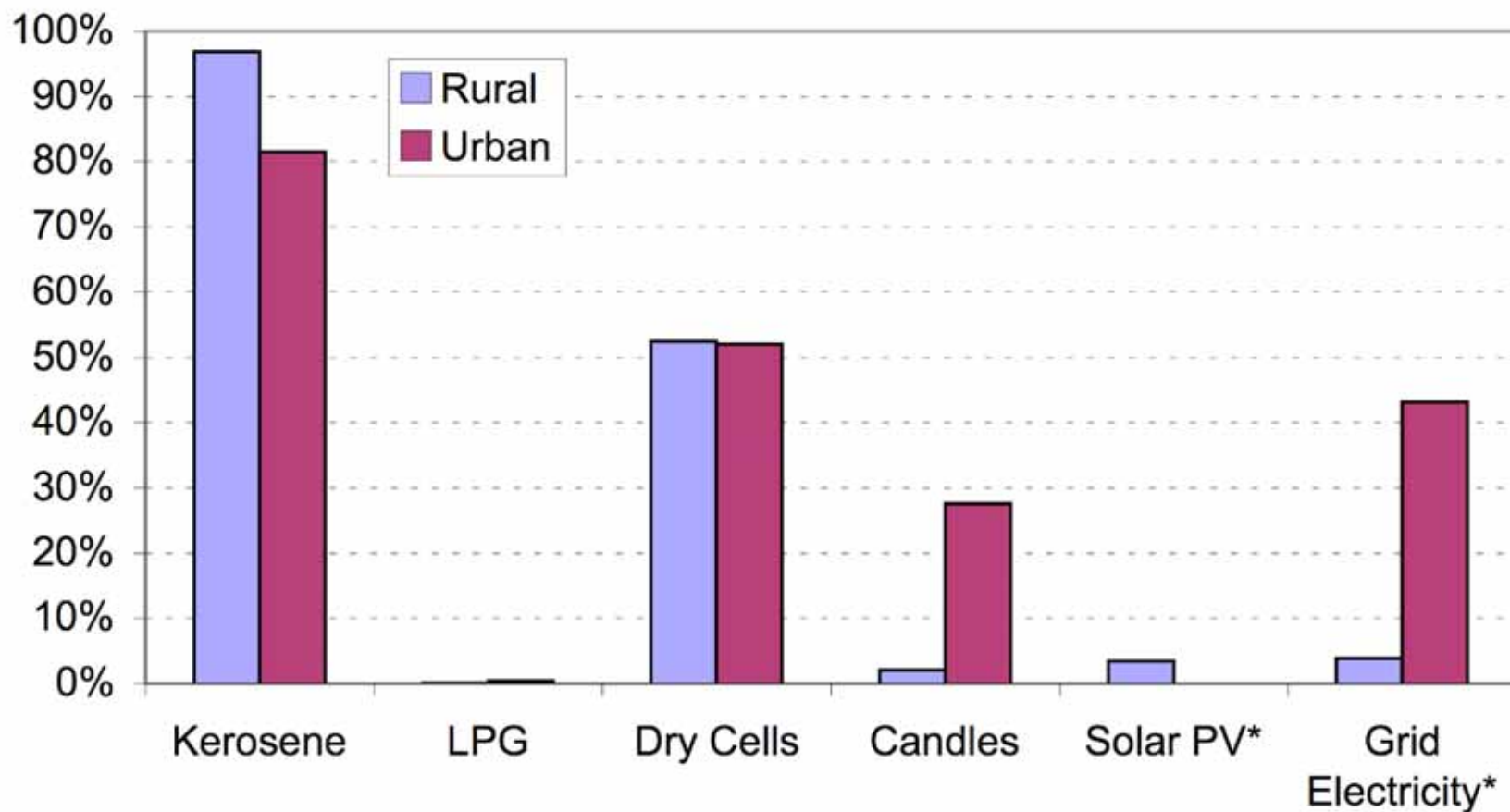
Even Fuel Wood is Used for Lighting



Nepal

Off-Grid Households Use Multiple Types of Light Sources

Use of Energy for Lighting: Kenya (2001)





The Burden of Fuel-based Light



Huangshan, China



India: propane lamp

Precursors

Electrification: Not always effective



**Yunnan
China**

“Electrification” Is Often Ineffective for Lighting



(Yunnan, China)

Traditional Solar-Fluorescent Systems Have only 0.2% Market Penetration (and less at the bottom of the pyramid)



Photo: Evan Mills ©

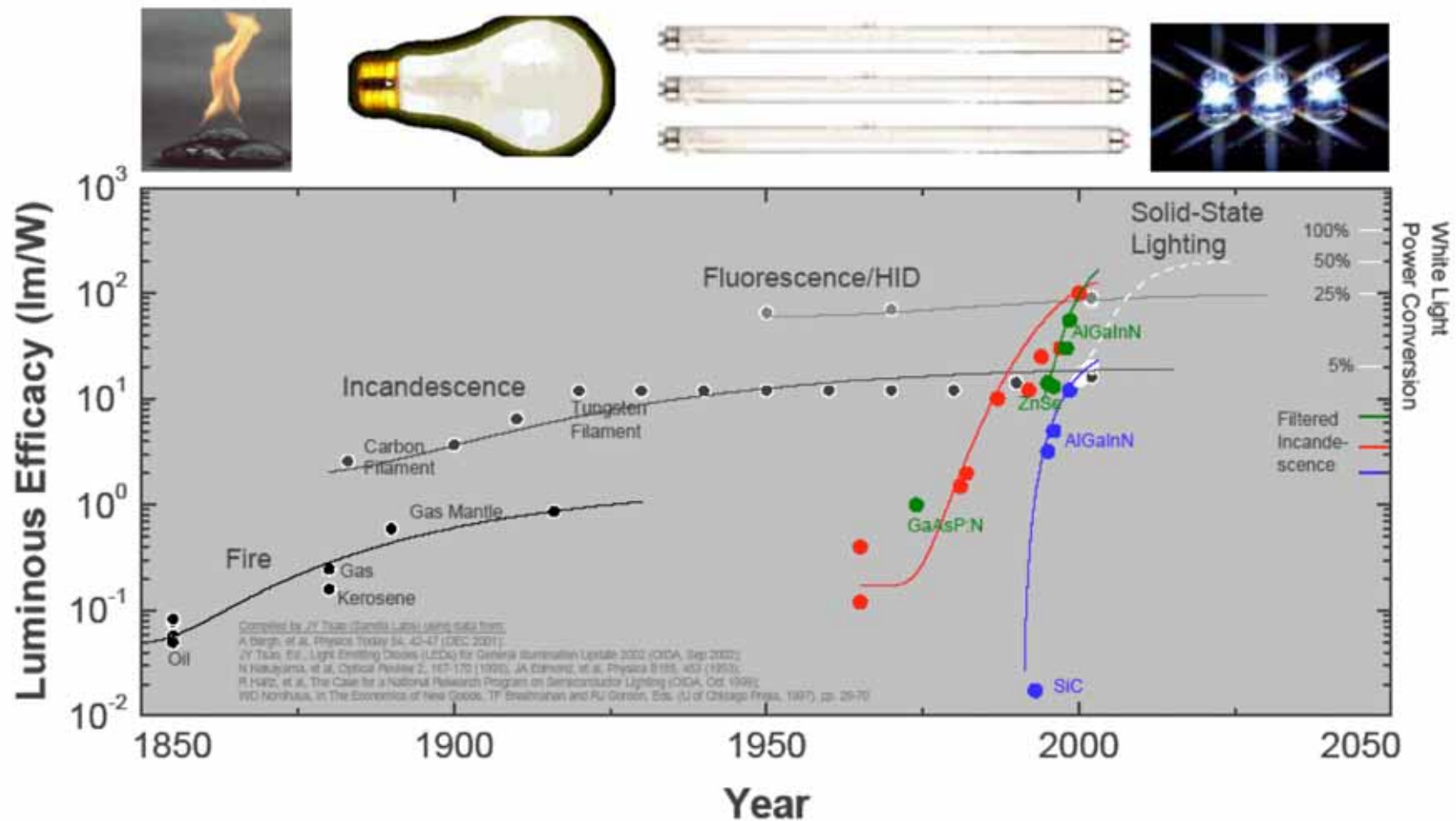
Solutions

White Light-emitting Diodes (“LEDs”)

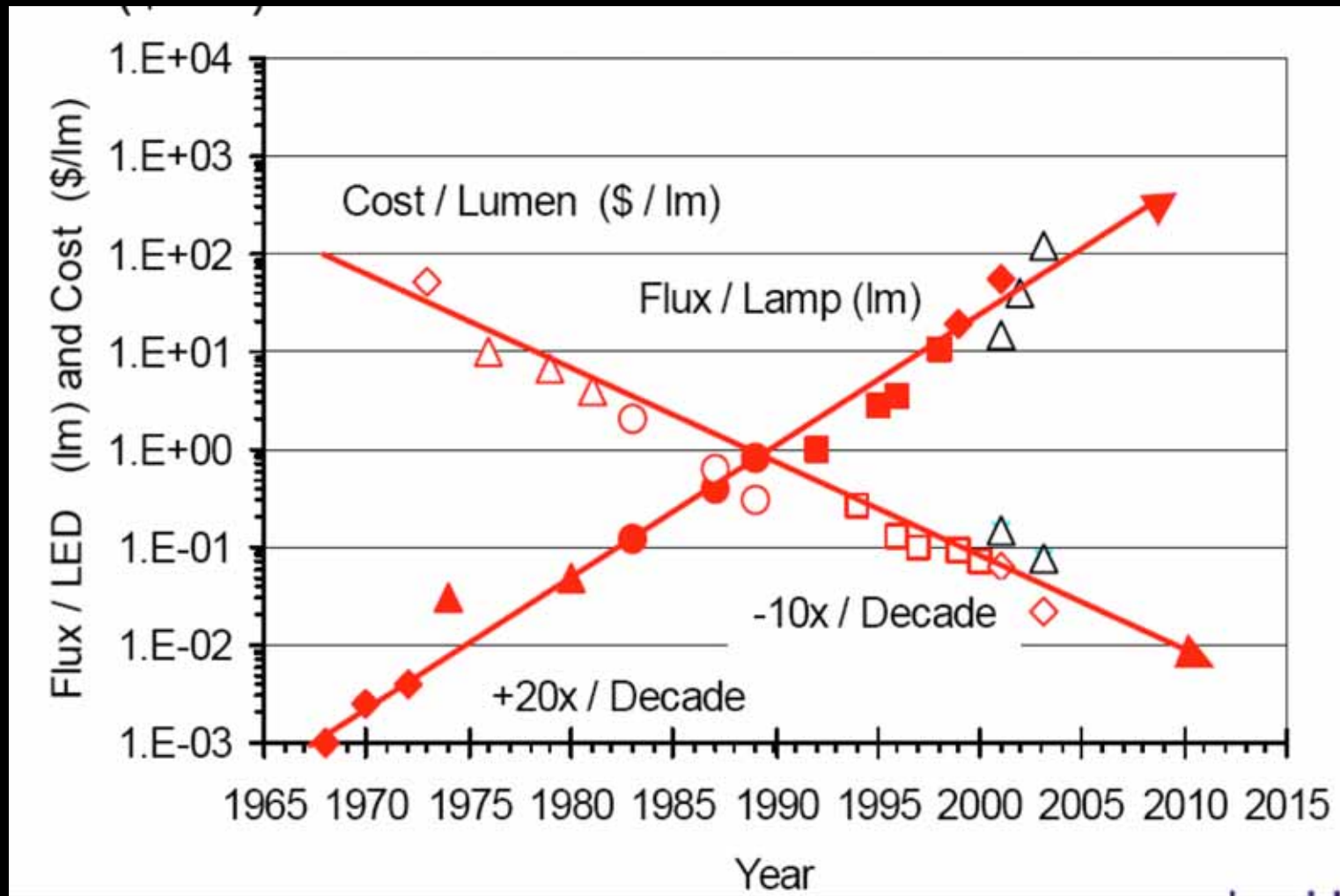
- Efficient
- Long life
- Low voltage
- Directional
- Portable
- Rugged
- Common batteries
- 10-100x the service level of flame light



White LEDs: Leapfrogging Efficiency



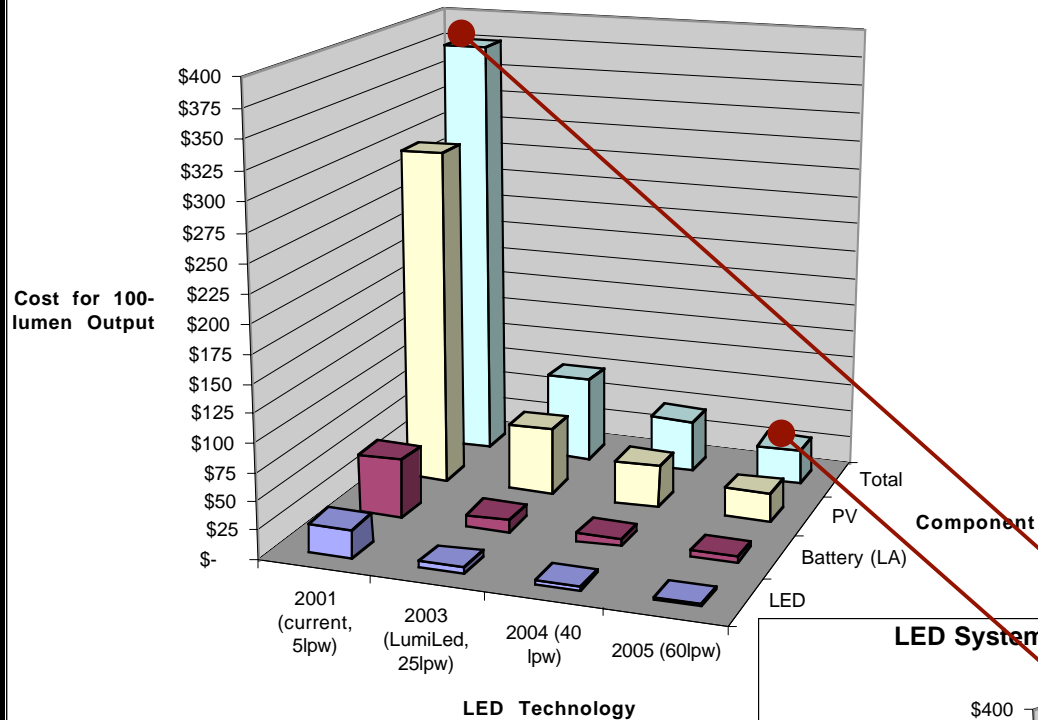
LEDs: Rising Light Output; Falling Cost



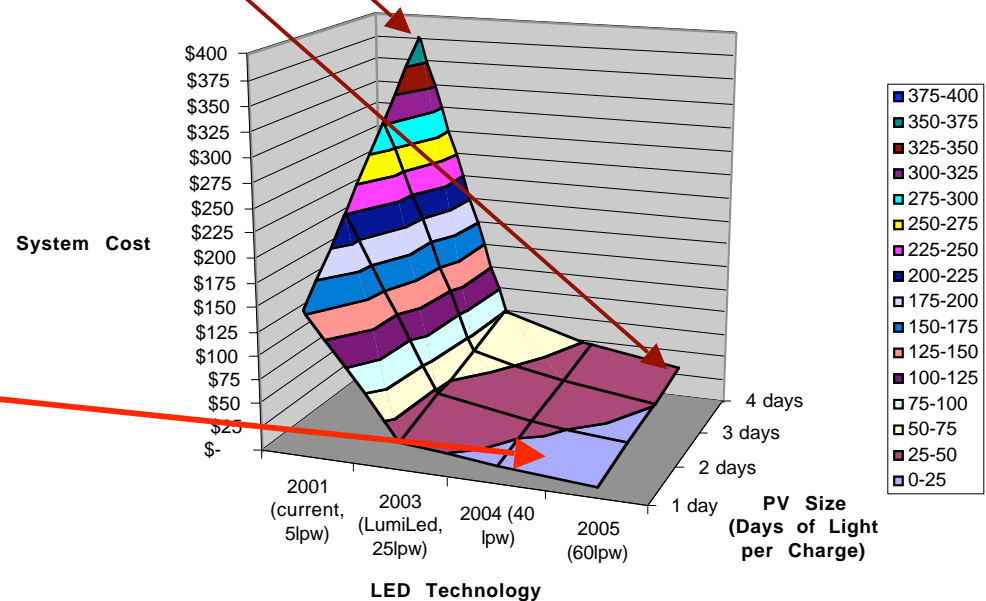
Source: White Lighting (Illumination) with LEDs, Werner Goetz, Fifth Int'l Conf. on Nitride Semiconductors, ICNS-5, Nara, Japan, May 25-30, 2003.

Economic System-Level Analysis

LED System Component Costs: 50 lumens



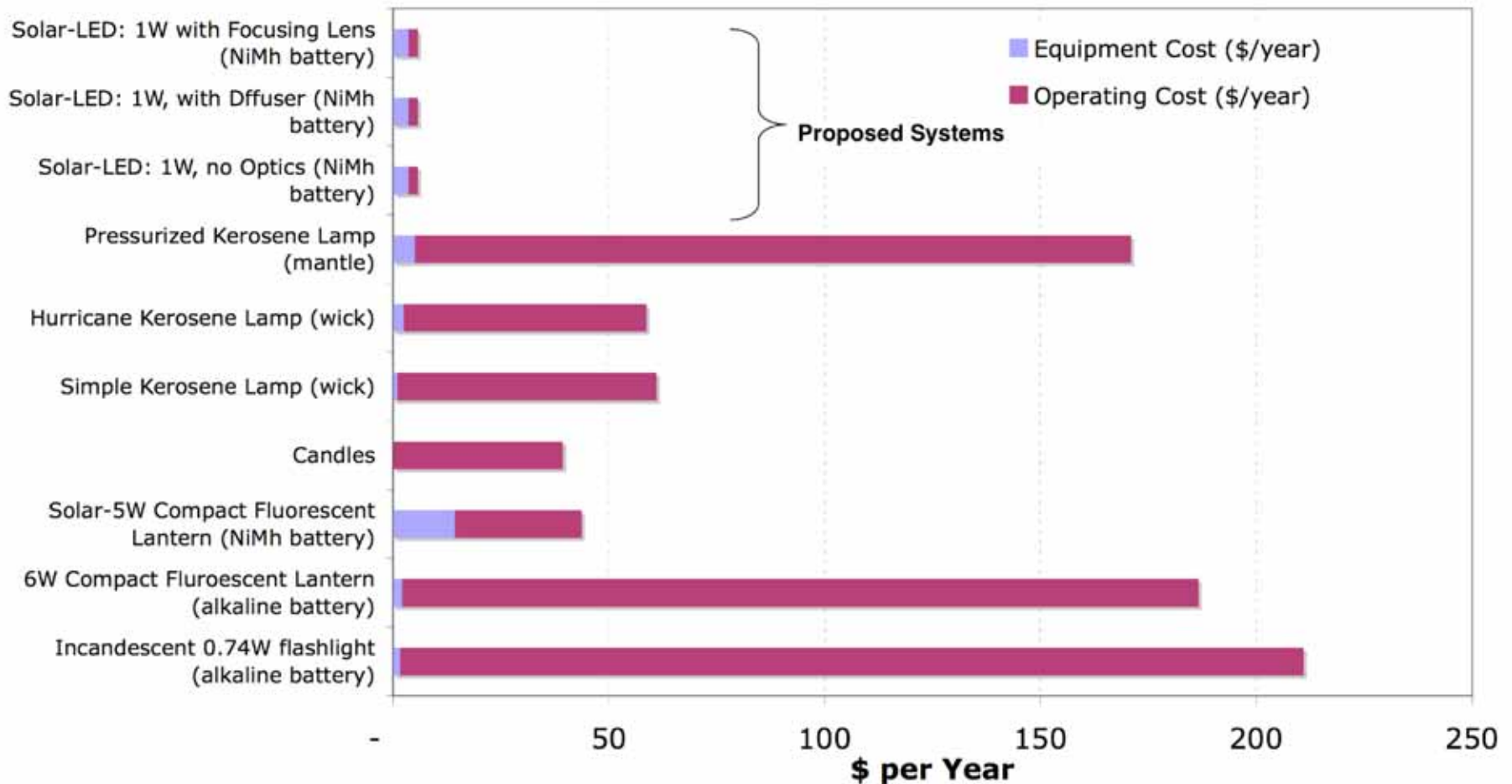
LED System Costs as Function of Light Output: 50 lumens



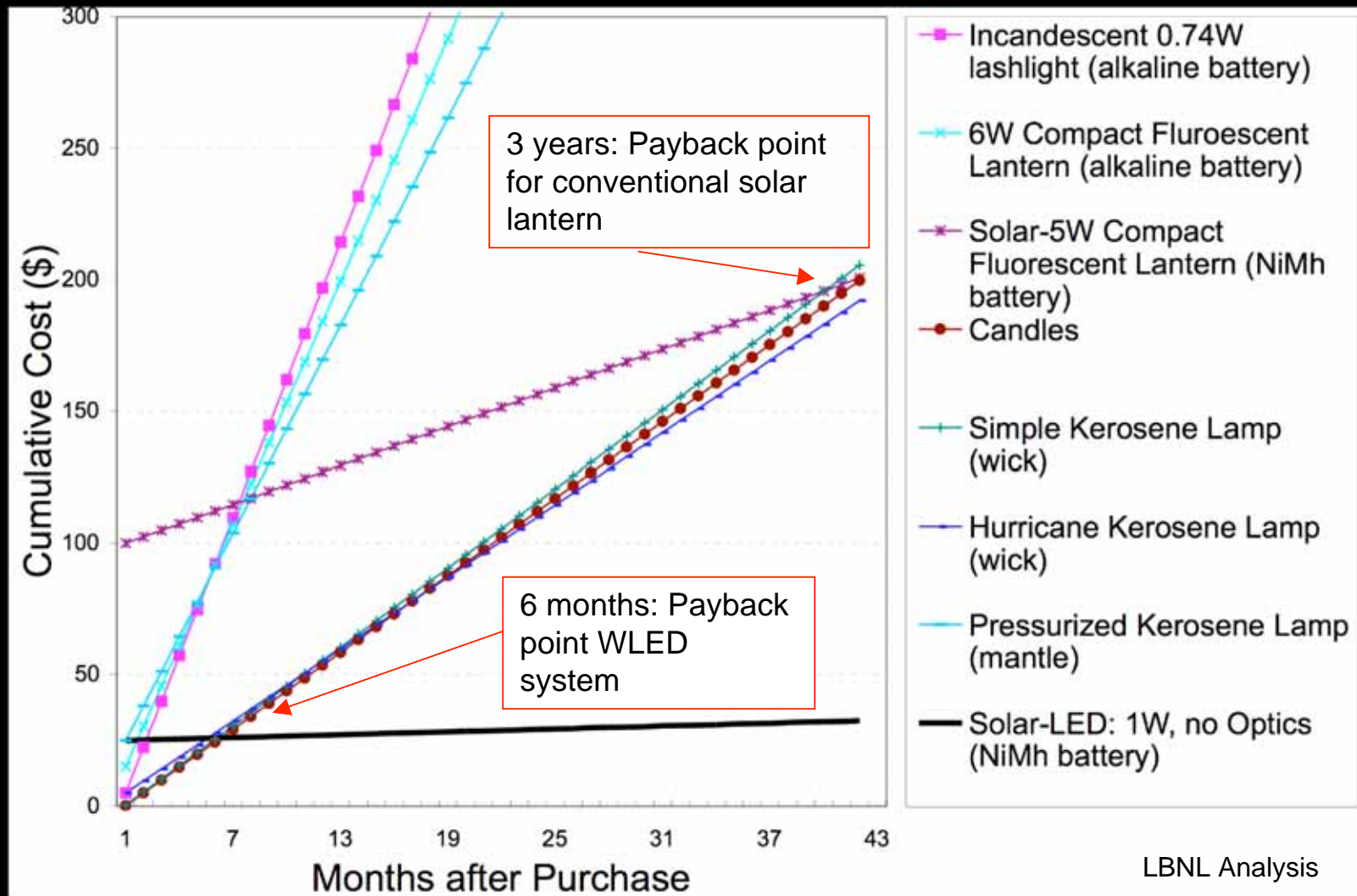
Current
Costs

Vastly Lower Cost of Energy Services Compared to the Competition

Off-Grid Lighting: Comparative Total Costs of Ownership
(assumes 4 hour per day operation)



Total Cost of Ownership: LED Payback is 1 month to 2 years



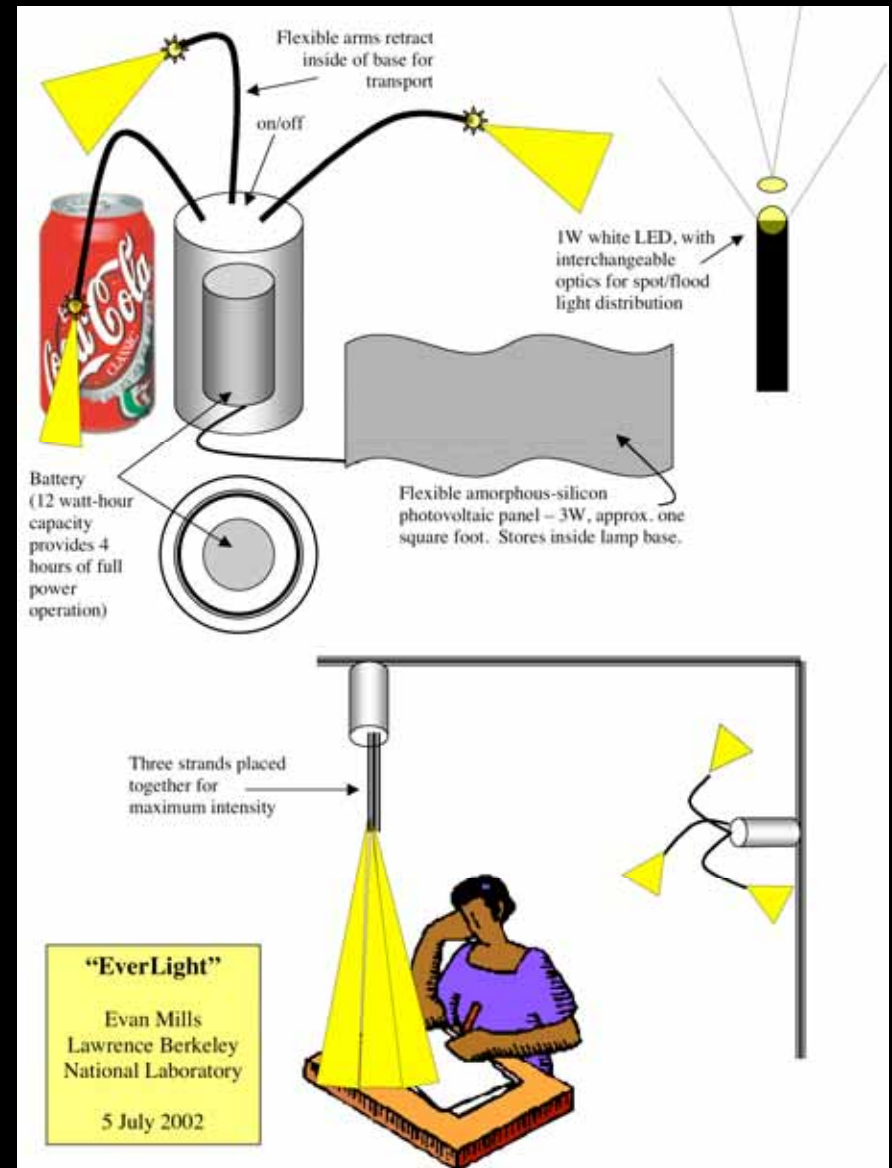
Prototyping to Deployment

Concept Development

LEDs - Desirable Properties:

- Efficiency
- Low voltage
- Directionality
- Portability
- Ruggedness

[Issues: glare; heat]



Stanford + IDEO + LBNL (and others from Silicon Valley)



Side-by-Side Comparisons



Tanzania: fruit seller - flame [left]; 1-watt white LED [right]



Tanzania: sandal seller - flame [left]; 1-watt white LED [right - no flash]

Feedback from End Users



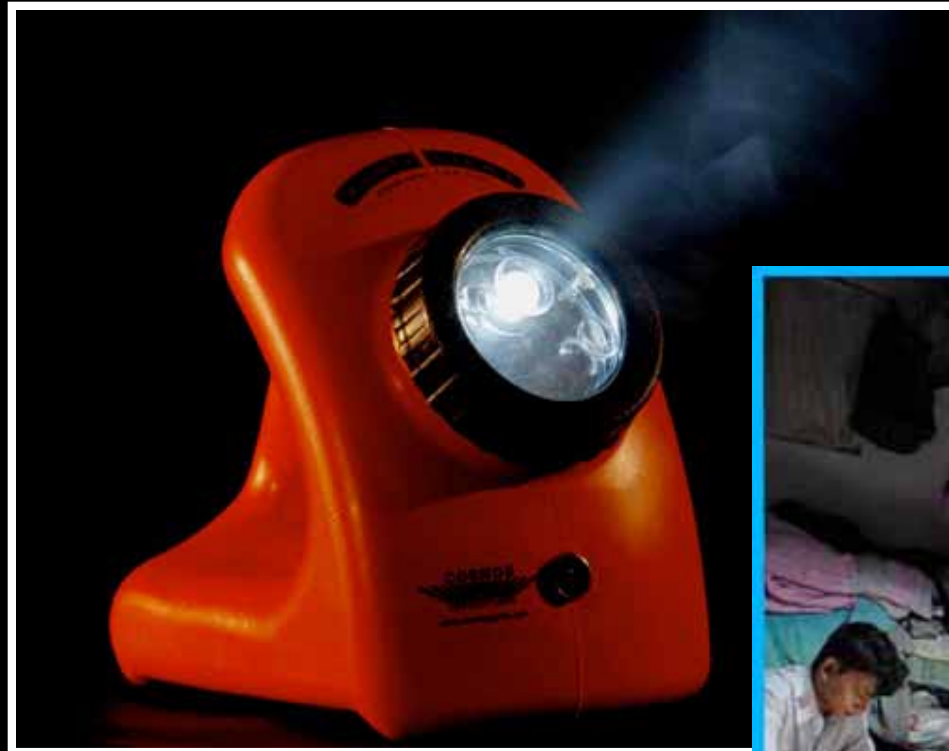
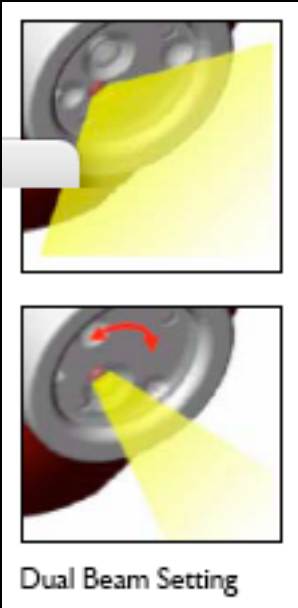
Kenya: vegetable stand
Kibera slum

“I can see the money!”

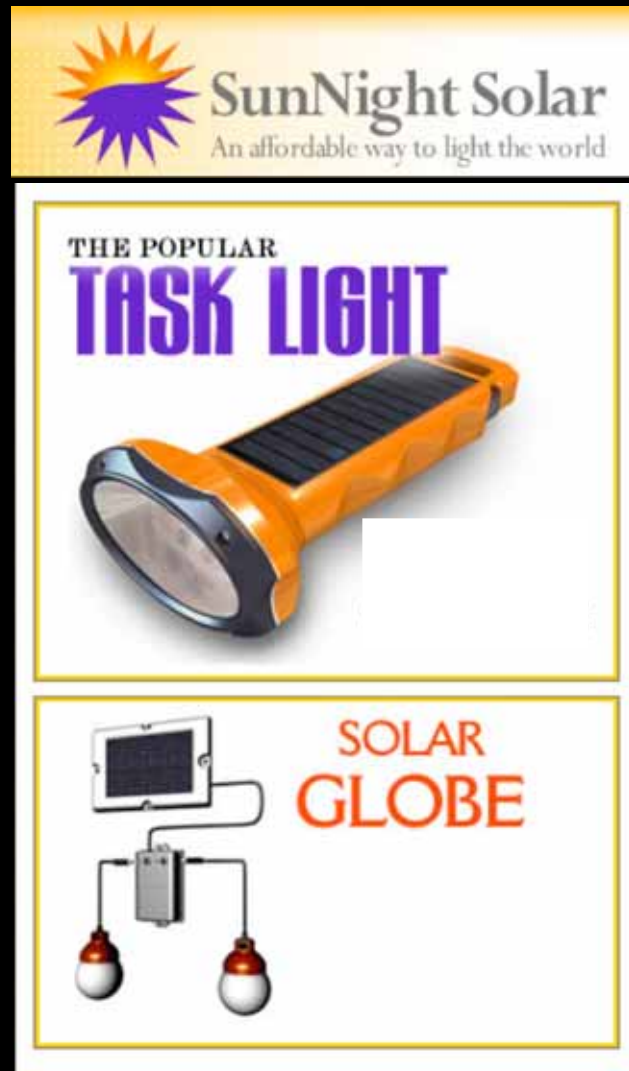


Tanzania - street market

Commercial Products: Cosmos-Ignite Lantern



Commercial Products: SunNight “Torch”



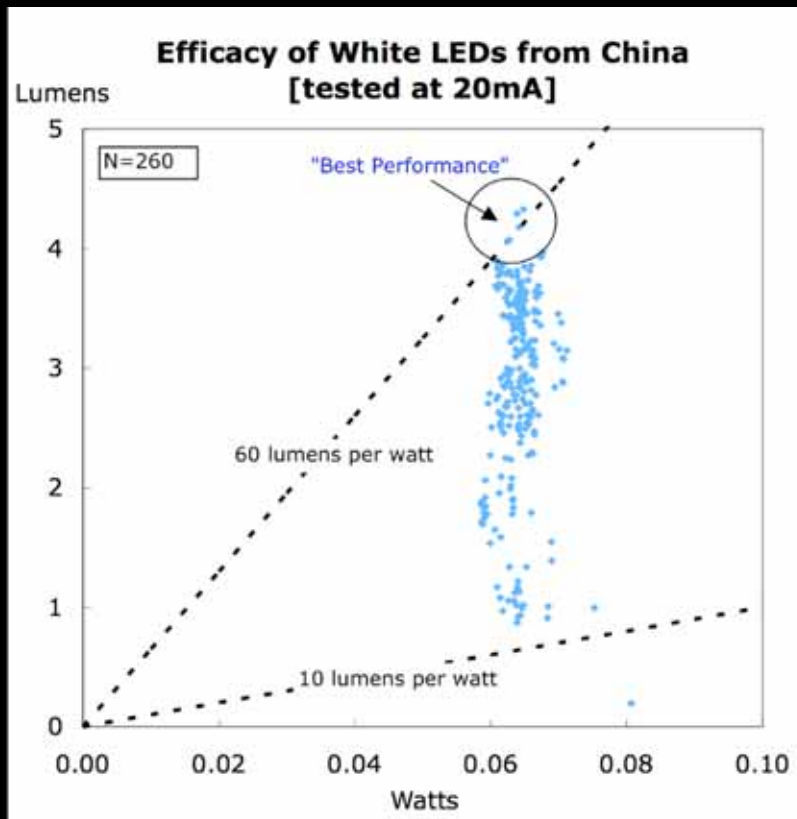
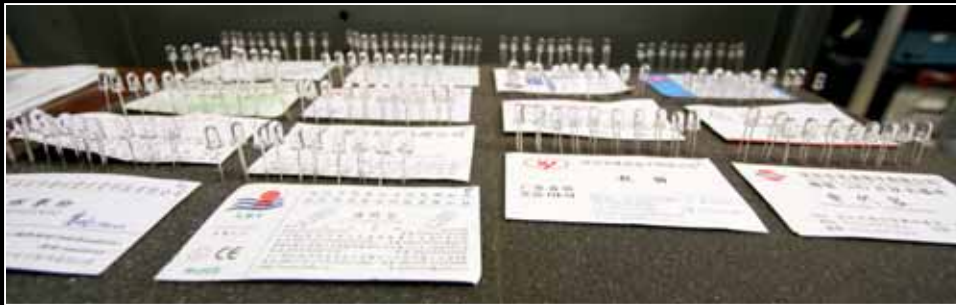
Product Quality Issues

Approaches to Off-Grid Lighting Product Evaluation

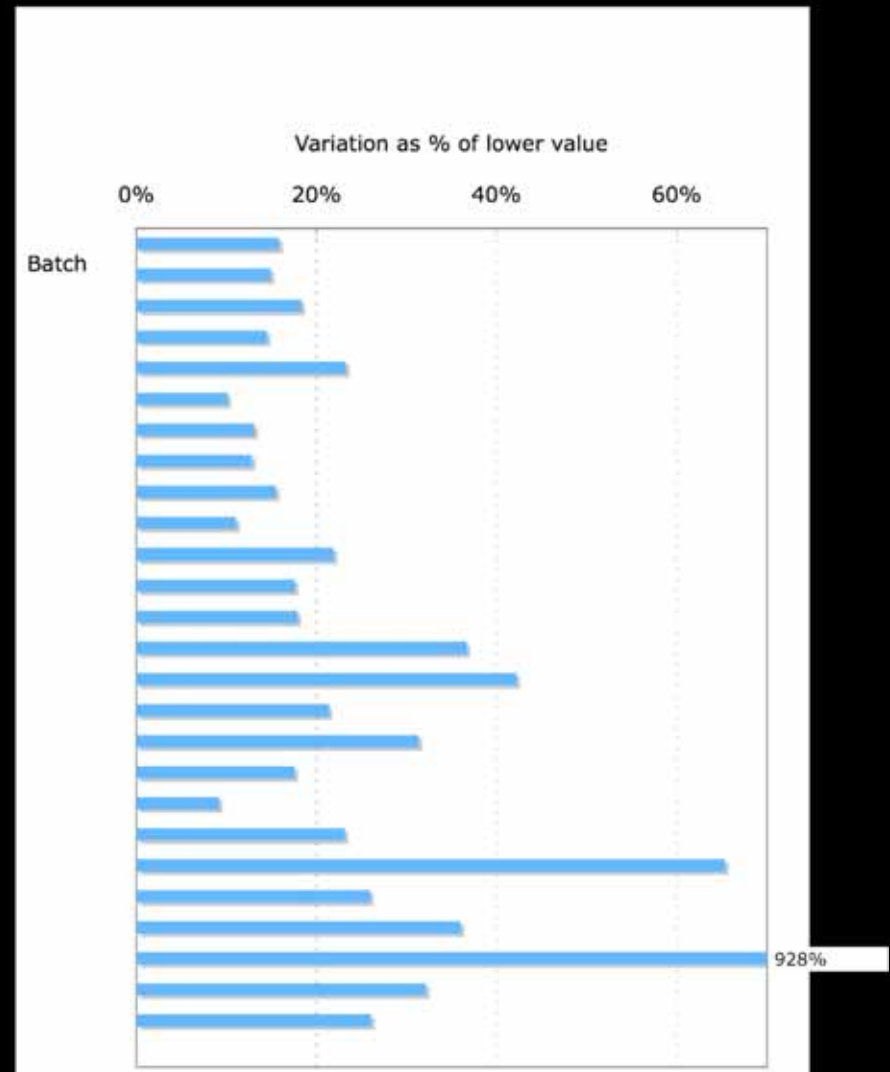
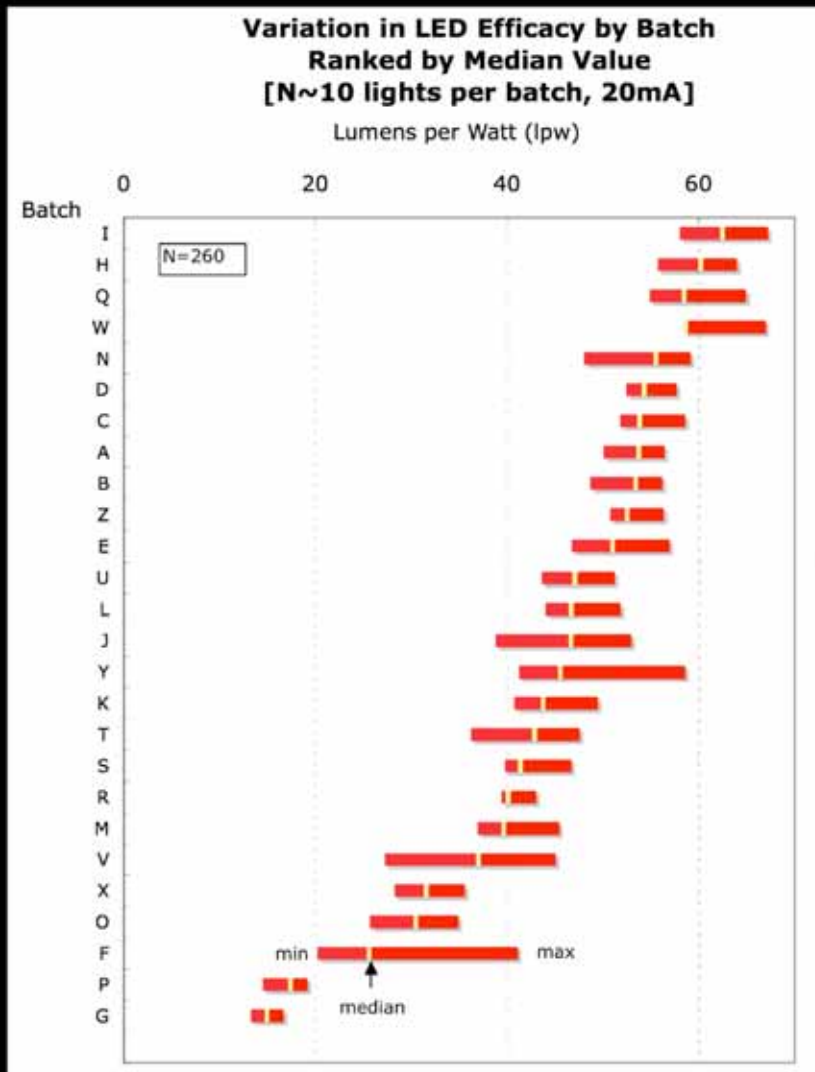
Evan Mills (LBNL) and Arne Jacobson (Humboldt State University) - 11/2006

- Eight preliminary examples
 - Baseline Lighting Systems
 - Kerosene lantern light output
 - Using “Hobo” monitors to document actual kerosene lantern usage patterns
 - Non-rechargeable battery life
 - Alternative Systems
 - Lighting service levels for LED systems
 - Light depreciation from CFL lantern
 - Asymmetry of light output from an LED-PV system
 - Rechargeable battery output: rated versus measured
 - Solar cell output: rated versus measured

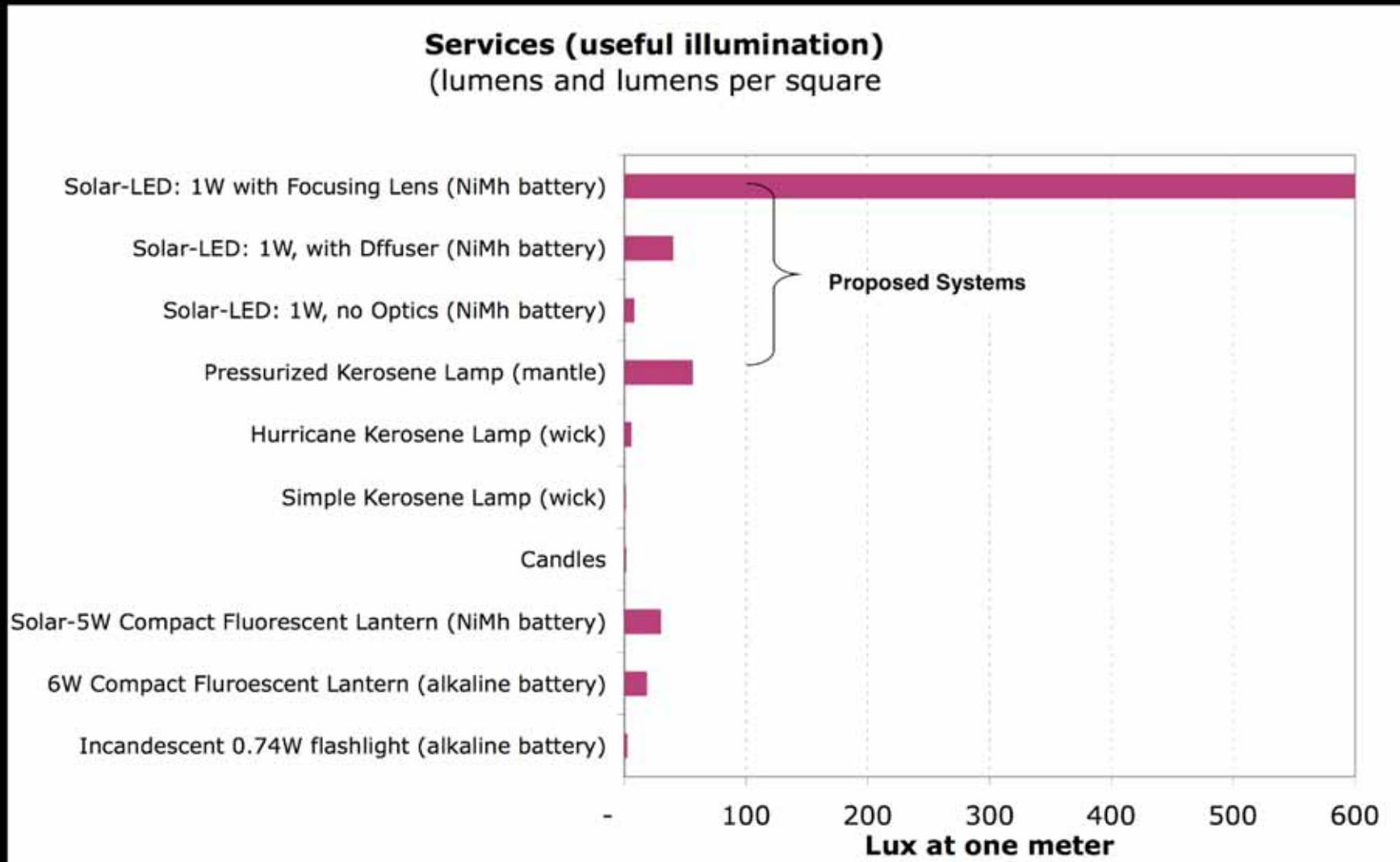
(In)efficiency of LED Light Sources



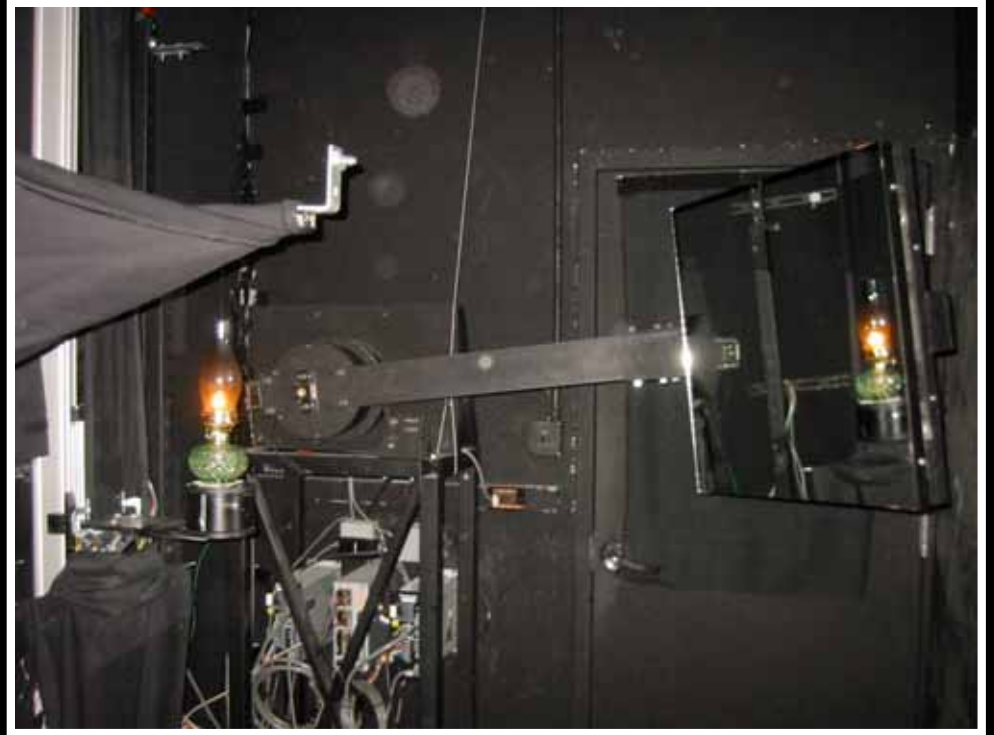
Inconsistencies



... and Higher Energy Service Levels



Kerosene Lantern Light Output Can Be Measured



Goniophotometer trials of
kerosene lanterns and LED
alternative systems

Kerosene Lanterns Provide Poor and Non-Uniform Service

Even in “optimal” conditions, provides only ~6 lux (at one meter distance), far below recommended levels

Fig 4a. Kerosene Lamp #2 Clean

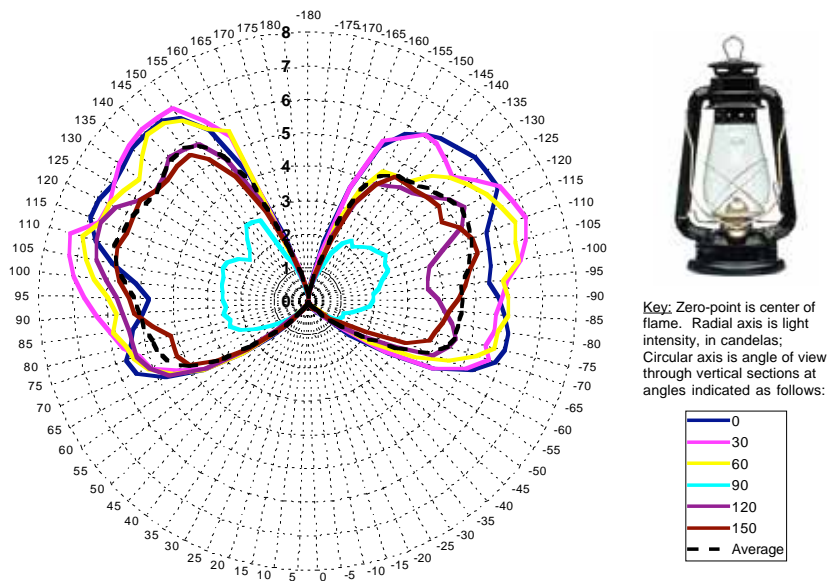
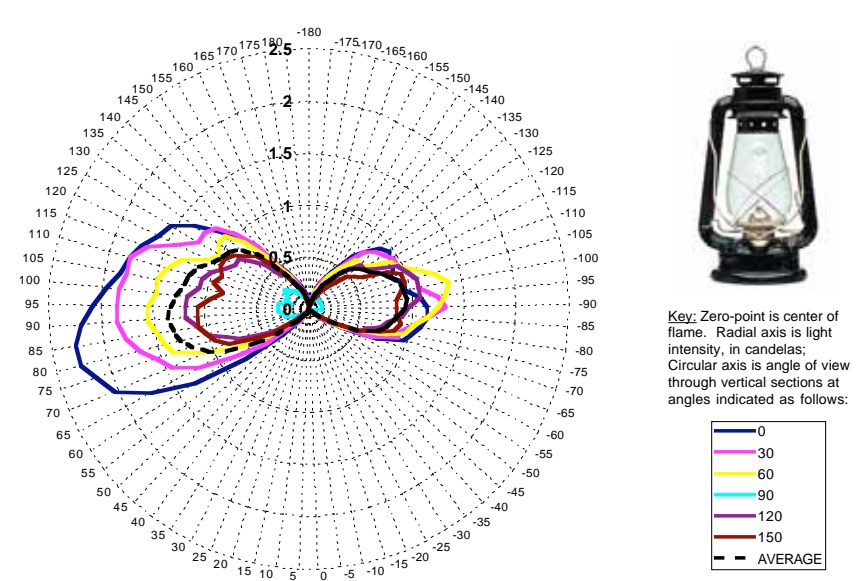


Fig 4b. Kerosene Lamp #2 Dirty



Photometric Results: LEDs

Superior Illumination to Flame-Based Lanterns

Fig 8a. 1-watt White Luxeon LED @ 350mA,
without Optics
candela = Lux at 1 meter

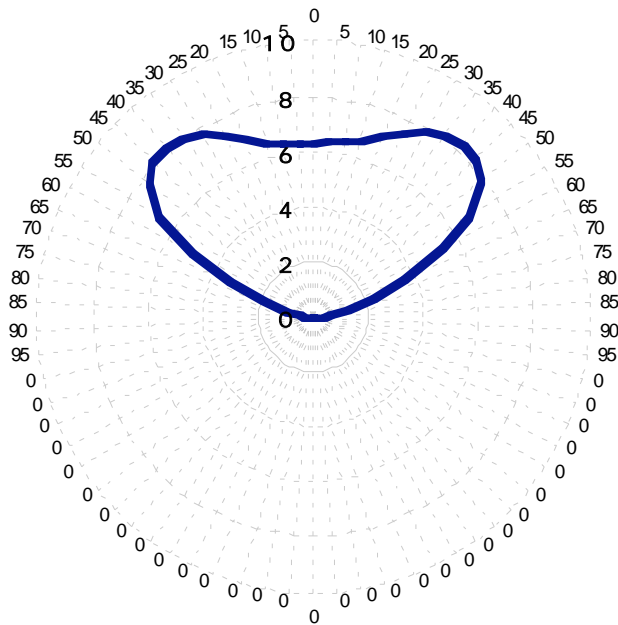
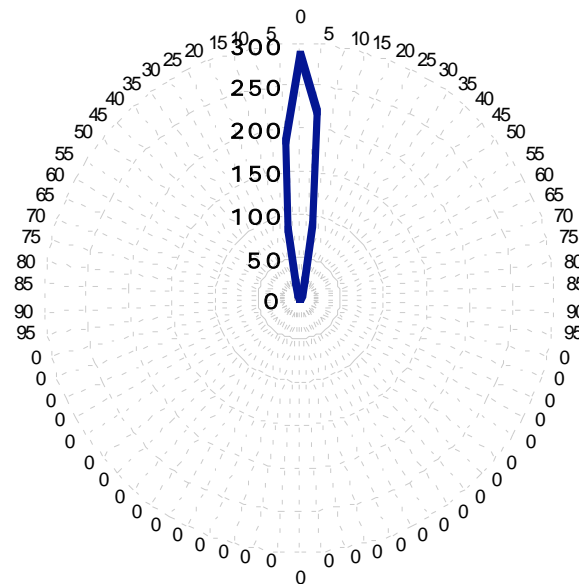


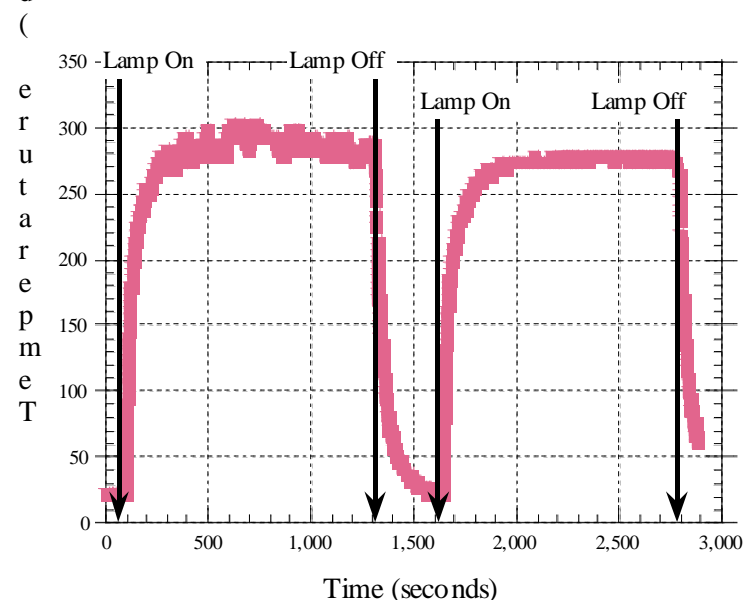
Fig 8b. 1-watt White Luxeon LED @ 350mA
with Optics
candela = Lux at 1 meter



With optics, LED => 100x more useful lighting service than flame

LBNL Analysis

Baseline Kerosene Lantern Use Can be Monitored

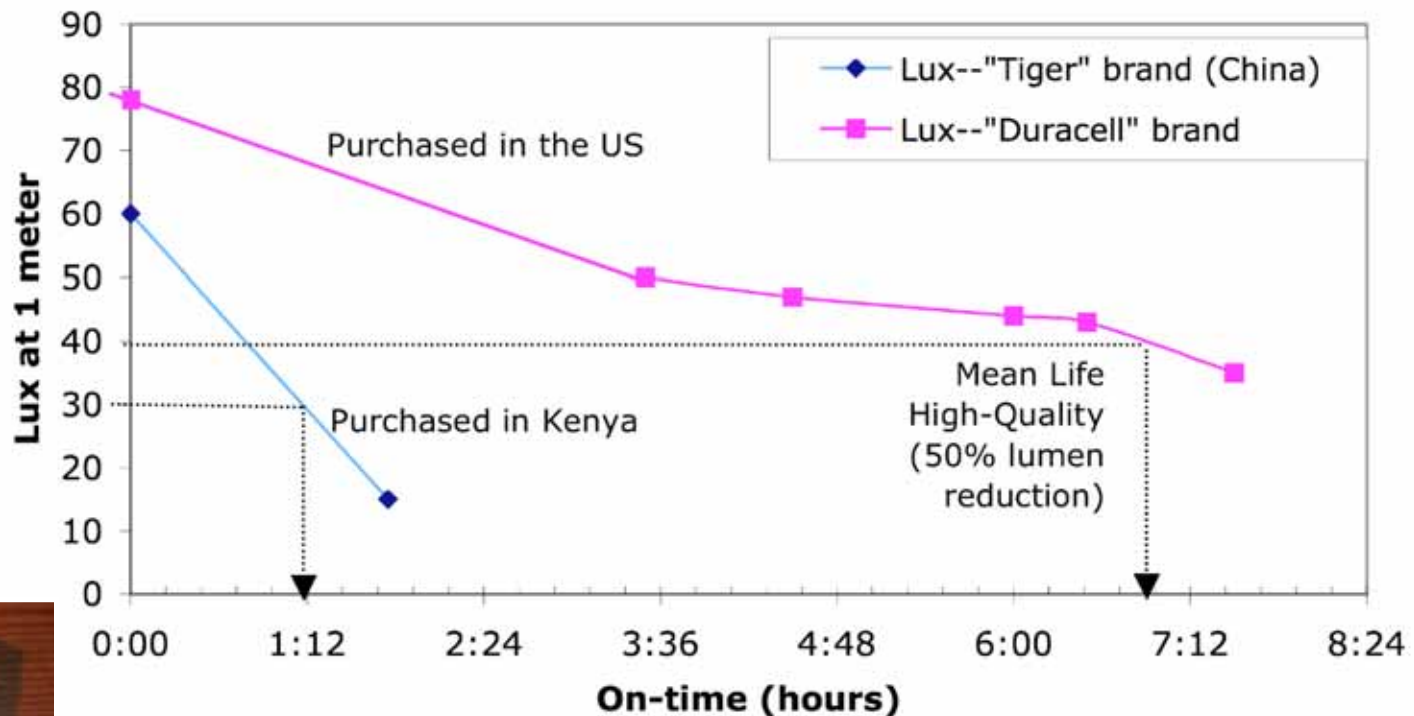


Temperature Response Curve for a Thermocouple Probe on Hurricane Lamp. Data acquisition by battery-powered “Hobo” logger attached to lantern (can store many months of data). Thermocouple used to determine when lamp was in use. The temperature indicated by the probe changed measurably within 5-10 seconds after the lamp was ignited or extinguished. This has not been done previously.

Low-quality Batteries are Currently in the Market

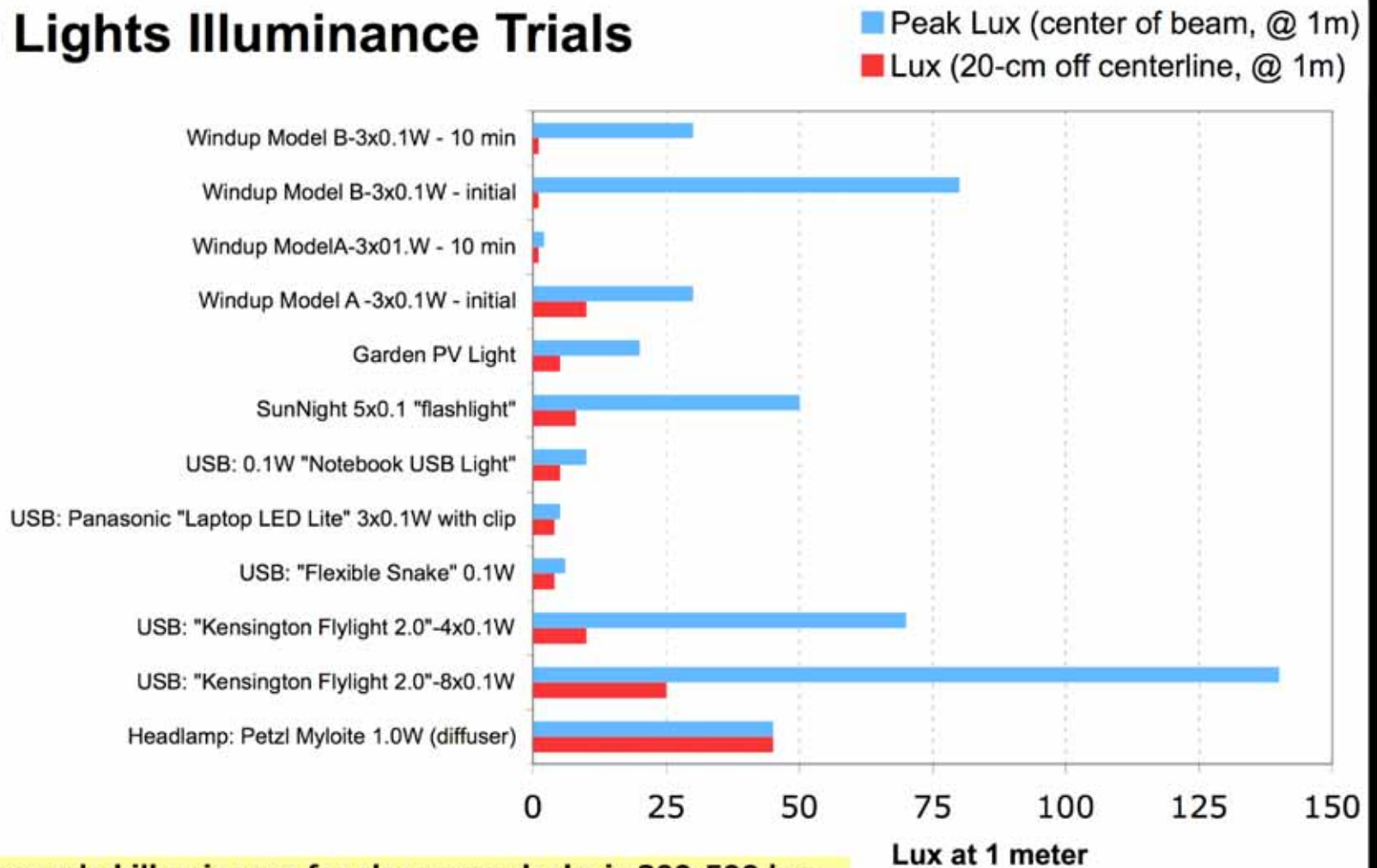


**Light Output for High- and Low-Quality Batteries
on Single Charge
[1W LED with Diffuser]**



Primitive LED System Light Output & Distribution Vary Considerably

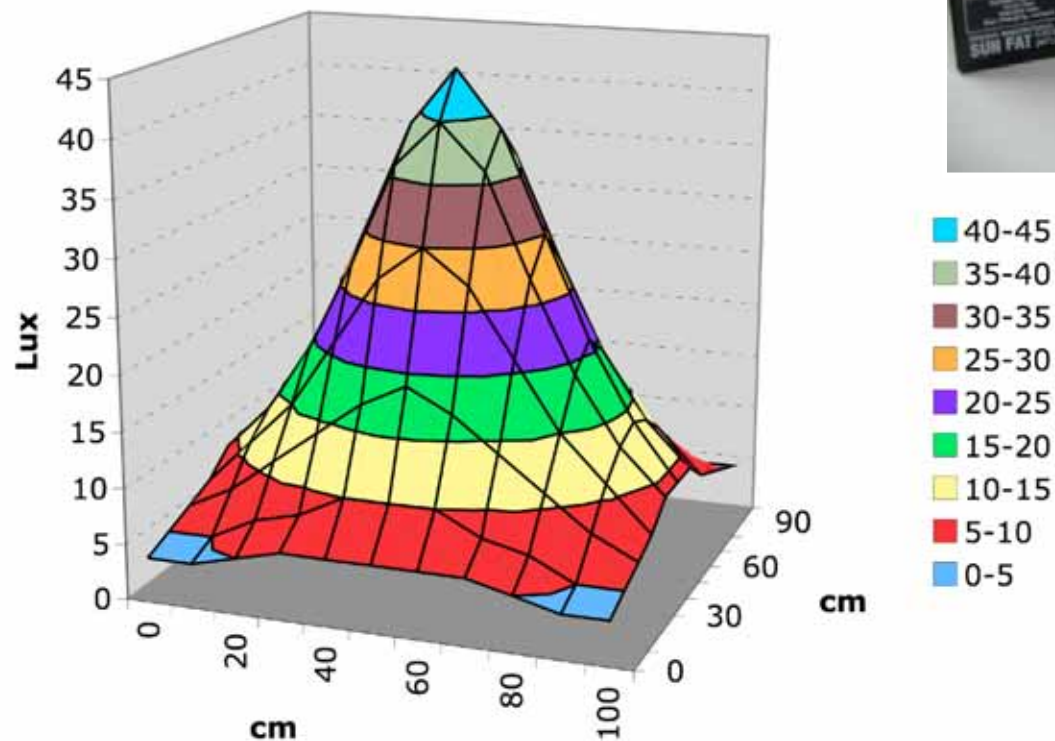
WLED Lights Illuminance Trials



IESNA Recommended illuminance for classroom desks is 300-500 lux

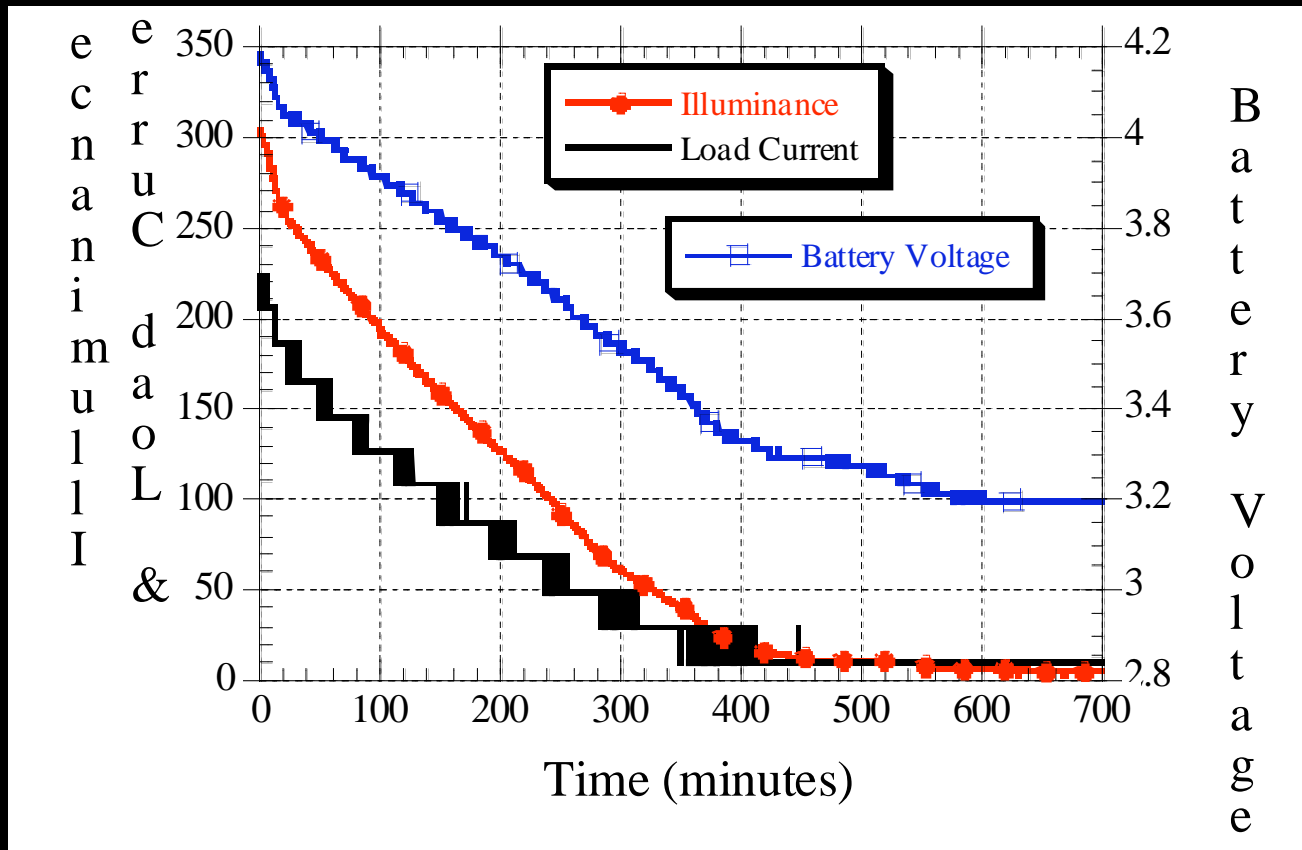
(non)Uniformity

**Illuminance Distribution: Foreverbright Lantern
(1 meter)**



Foreverbright Lantern

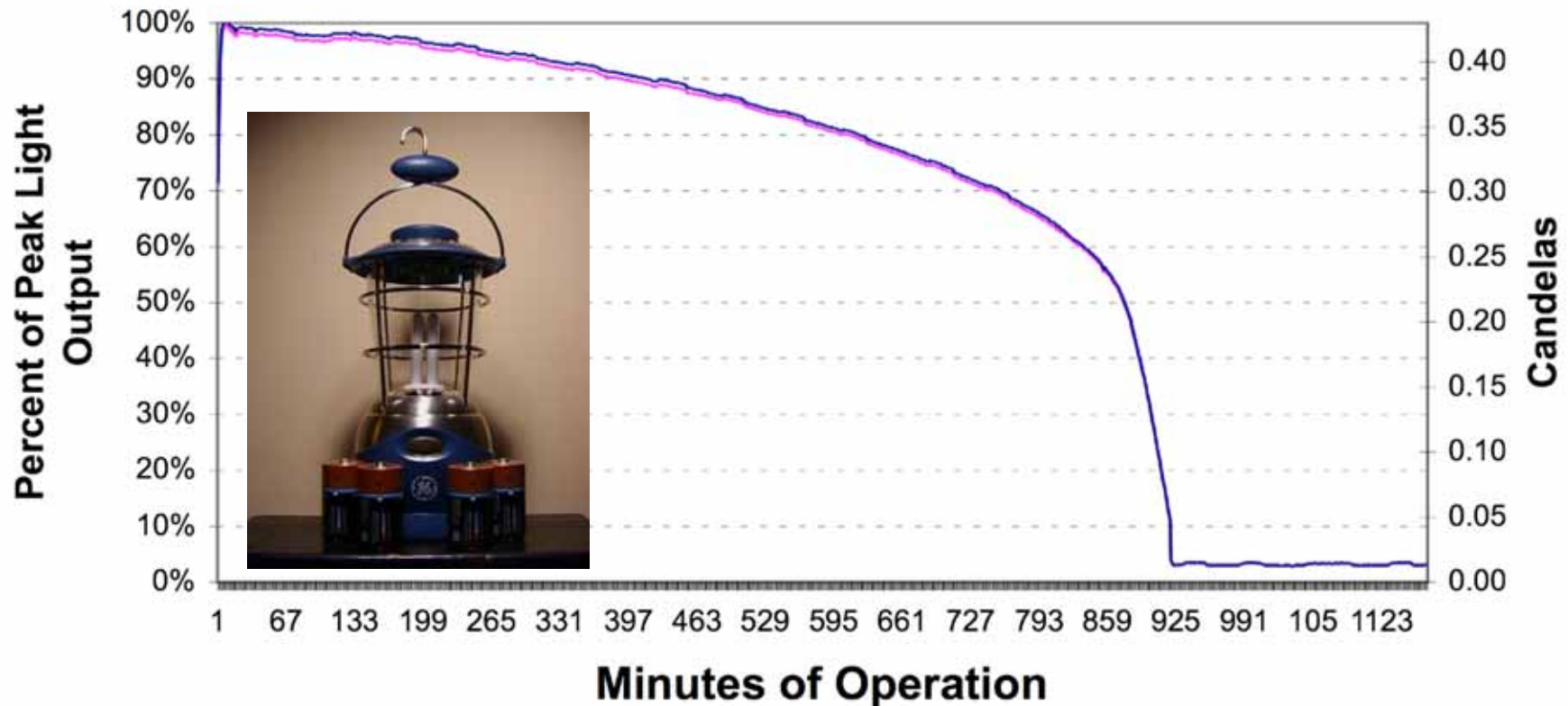
Light Degradation due to Lack of Current Regulation



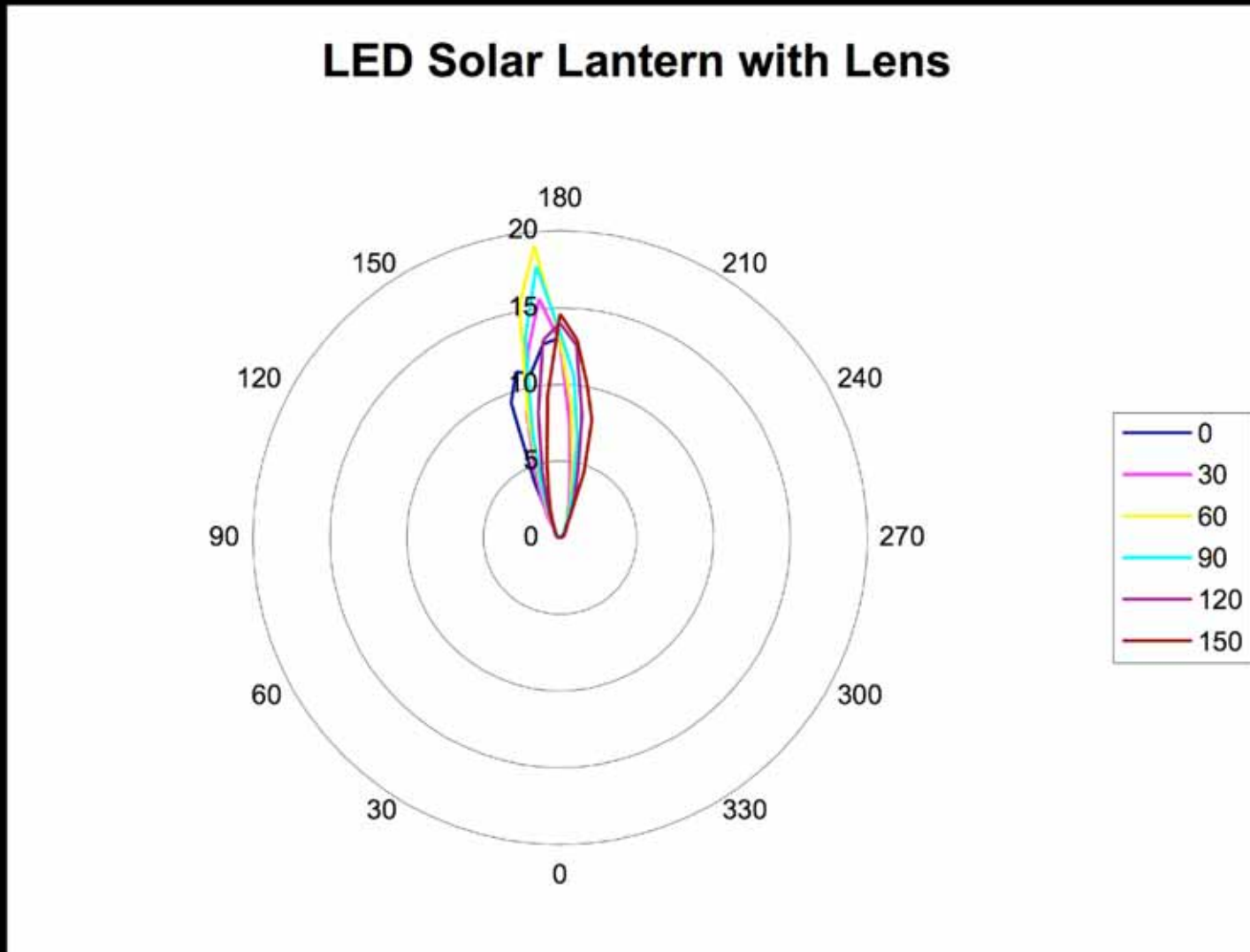
Battery Voltage, Load Current, and Illuminance Over Time for a YG-3302 Desk Lamp During Discharge. The lamp delivered at least 50 lux to the surface for just over five hours of operation. It continued to deliver light at lower lux levels for over five additional hours. The test was discontinued when the lighting level dropped to approximately five lux. The illuminance meter was directly below the light source at a distance of 22 cm.

Light Depreciation from CFL Lantern

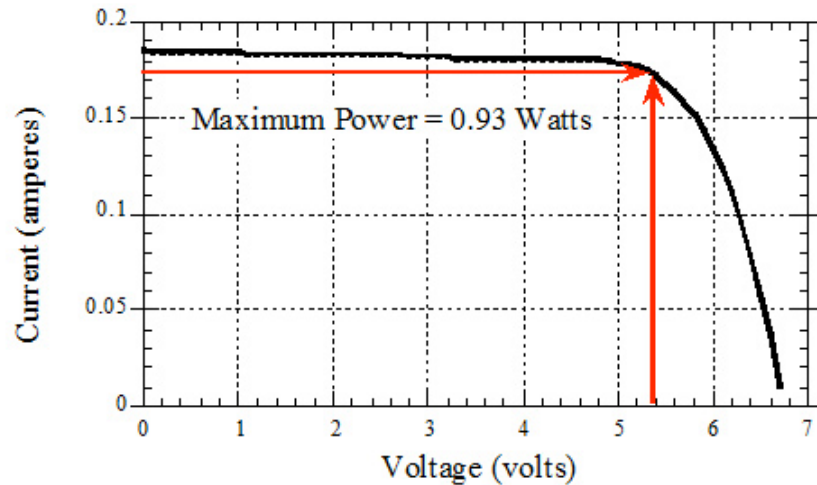
Lumen Depreciation: CFL Lantern



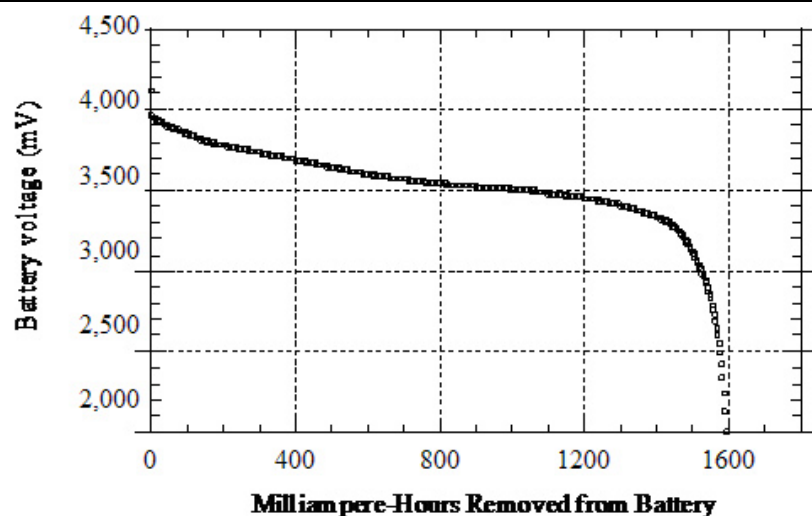
Asymmetrical Light Output from an LED Solar Lantern



Small PV and Battery Performance Can be Compared to Manufacturer Claims



Current-Voltage (IV) Curve for a One-Watt Rated Solar PV Module. The module delivered 0.93 Watts at standard test conditions of 1000 W/m^2 and 25°C . Not all modules will do as well.



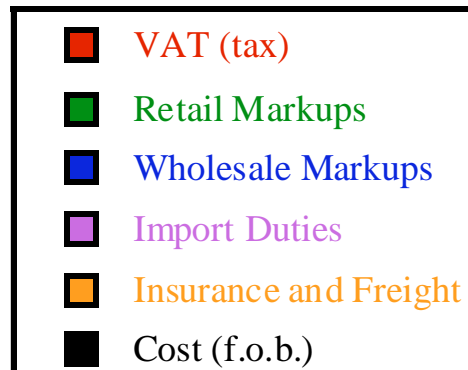
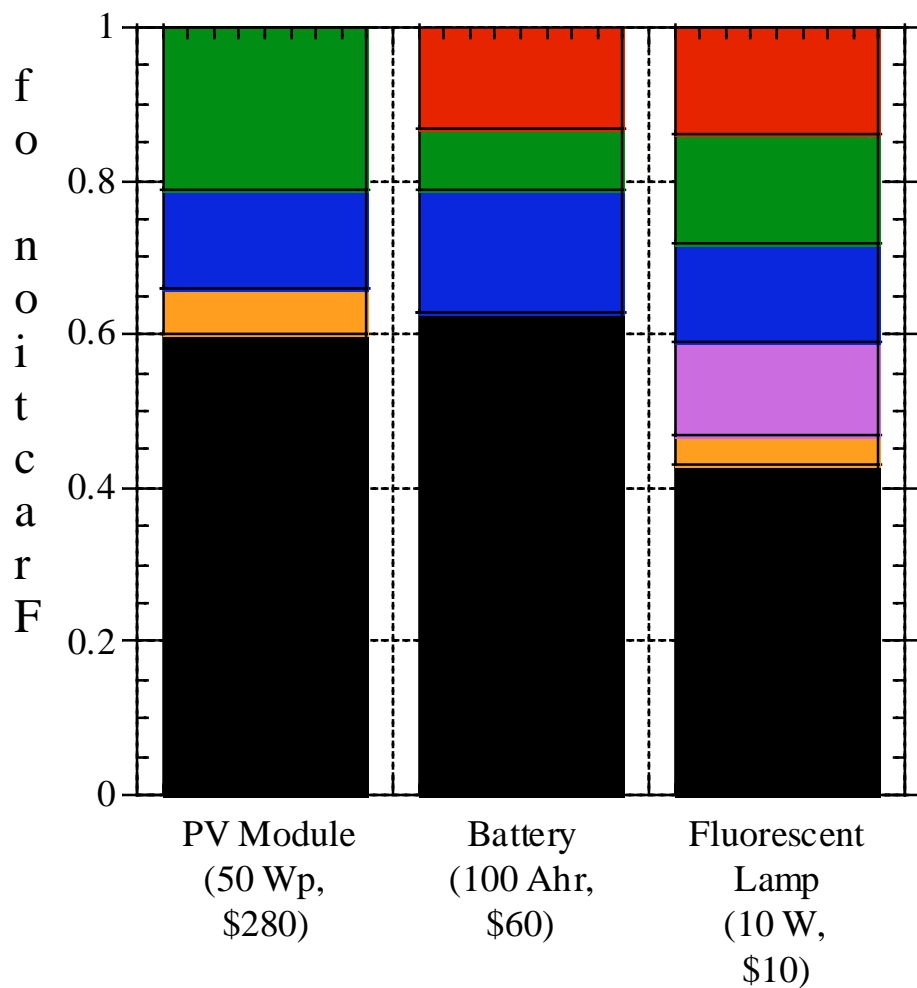
Discharge Curve for a 1600 Milliamp-hour (mAh) rated Lithium-Ion Rechargeable Battery. The battery delivered 1595 mAh at a discharge rate of 190 mA.

Counterfeiting



Market Deployment

Price Build Up in the Cash Market Supply Chain (Kenya)



Notes:

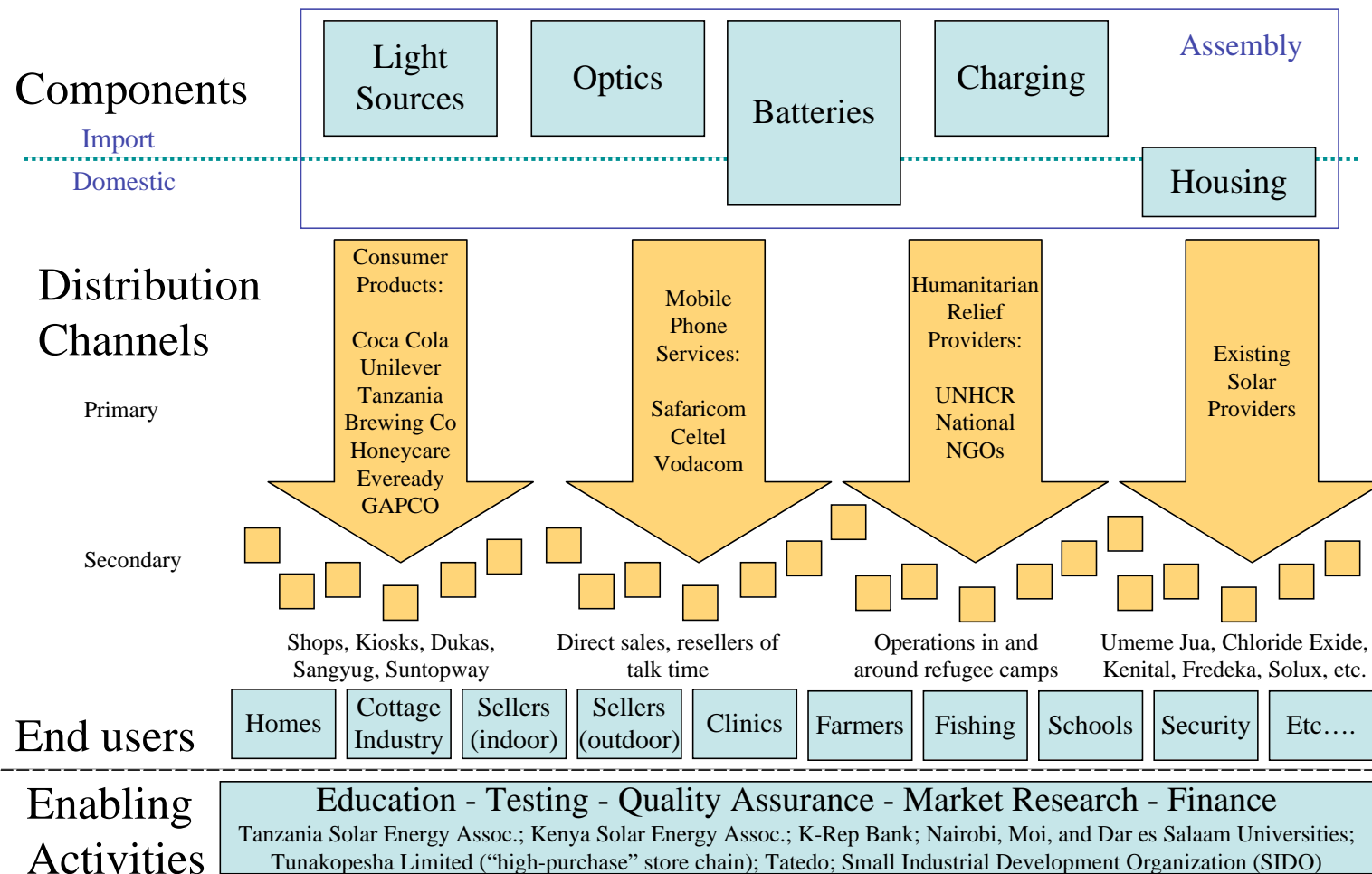
- PV modules sold duty and tax free
- Batteries manufactured in Kenya (no import duty)
- Lamps & electronics subject to 25% import duty

Source: ESDA, 2003

Mapping the Market

LBOP Project Concept: Applicable Value Chains

(Organizations listed are those we have already met with)



Existing Distribution Channels



Photo: Evan Mills ©

Off-Grid Lighting Supply Chains (dominated by kerosene)



Photo: Evan Mills



Photo: Evan Mills

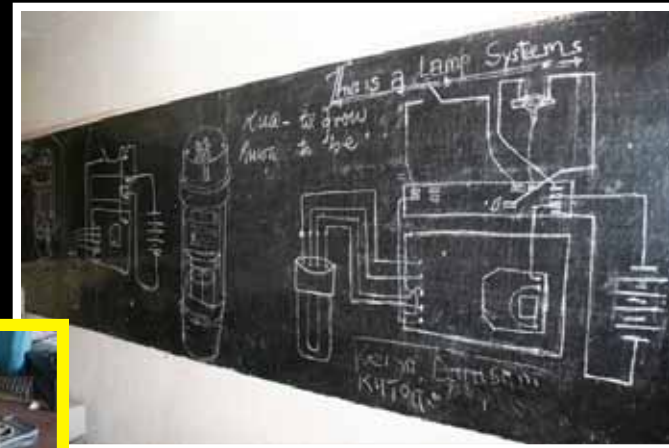


Photo: Evan Mills

Kerosene Commerce (Can existing sales channels be re-purposed?)



Northeast Viet Nam



**Building and leasing
solar-fluorescent
systems: rural high
school, Tanzania**



Photos: Evan Mills ©

Market Deployment

World Bank / International Finance Corporation

Lighting the Bottom of the Pyramid - <http://www.ifc.org/led>

- Project launched in 2006 in Sub-Saharan Africa
- \$7 million from Global Environmental Facility and other sources; 4-year life
- Engaging LED industry and other players; promoting competition and continued innovation
- Goal is 1 million units in the market after 4 yrs
- Involves detailed market tests of various products, coupled with quality testing, and technical feedback to manufacturers

Endorsement of IFC Project by Philips (using data from Mills)

Business, governments and NGOs are now actively engaged to address this unsustainable situation. “Lighting the Bottom of the Pyramid” is a global initiative to develop a commercial solution to bring modern lighting services to these 1.6 billion people, for example, by developing alternative off-grid lighting systems of higher quality and much lower energy requirements than the fuel-based systems. Business can clearly play a role here, because a 38 billion dollar market is attractive. But since this market – as many markets for low-income people in developing countries– is not very well known or explored, it is essential that governments, international organizations such as the World Bank, NGOs and various companies get together to work out the right business models. That’s exactly what we are doing at the moment under the aegis of the International Finance Corporation.

Gerard Kleisterlee, President and CEO of Philips
October 2006

Research Questions

- Better characterization of baseline
- Intra-household decision-making
- Evaluation of actual carbon savings
- Quality and performance
- Market segmentation
- Synergisms with cell-phone charging
- Business models

More Information

EMills@lbl.gov

<http://eetd.lbl.gov/emills>

